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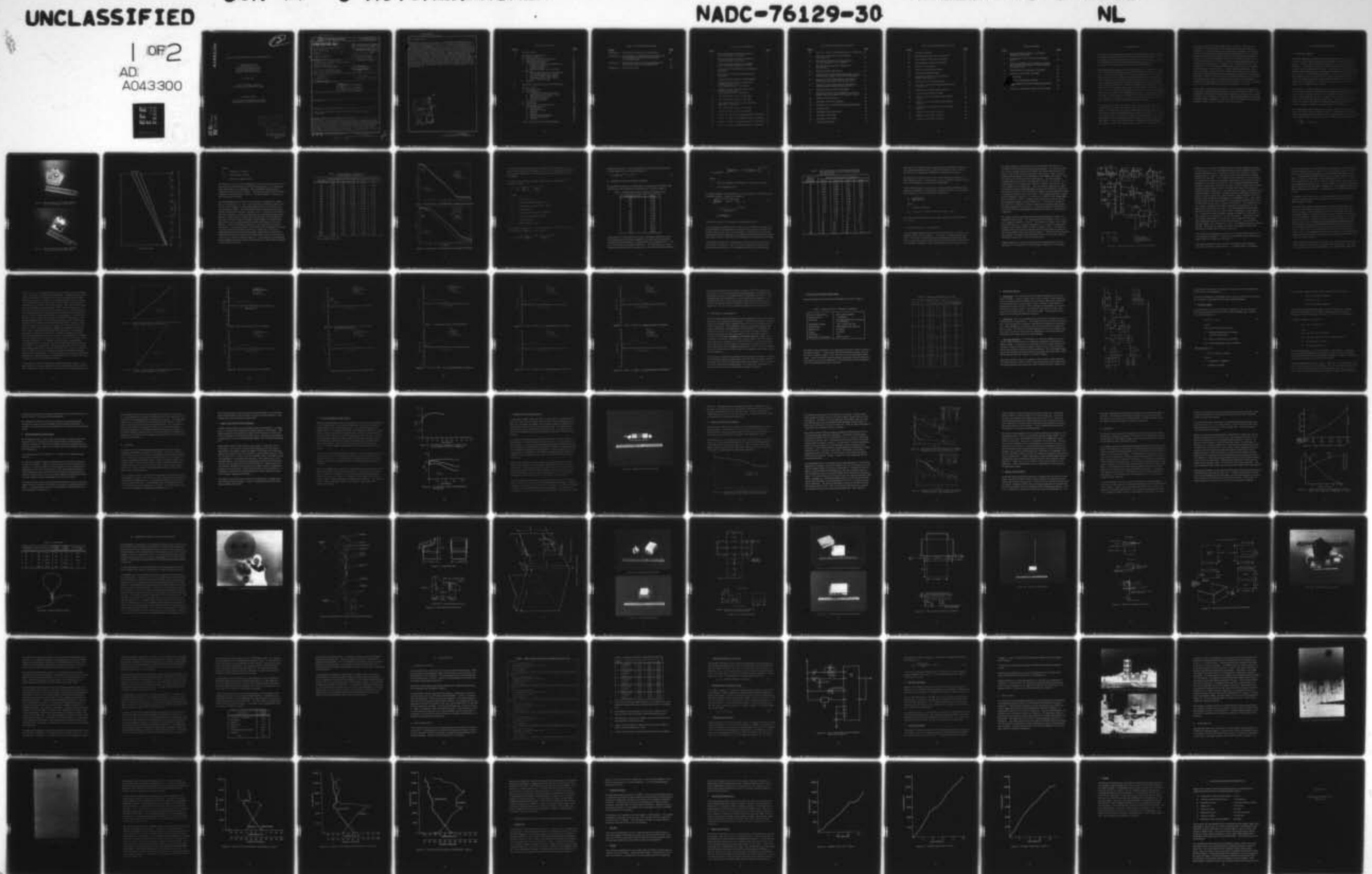

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MINIATURE METEOROLOGICAL BALLOONSONDE

C. MOTCHENBACHER
HONEYWELL INC.
DEFENSE SYSTEMS DIVISION
600 SECOND STREET NE
HOPKINS, MINNESOTA 55343

30 JUNE 1977

FINAL SUMMARY REPORT
FOR CONTRACT N62269-76-C-0368

PREPARED FOR

NAVAL AIR DEVELOPMENT CENTER
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The purpose of this program was to demonstrate that it is possible to build a light-weight miniature meteorological sonde (minisonde) which can be borne aloft by a 30-gram latex balloon. During this program, 85-gram minisondes were built and successfully launched with 30-gram balloons. The program was broken down into two parts - the assembly of five minisondes and the launching/data reduction for these minisondes. The construction of a small, light-weight minisonde requires that new miniature sensors and

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20. Abstract (Cont.)

high-efficiency electronics be used. For temperature measurement, the standard rod thermistor was selected. For humidity measurement, the conventional VIZ carbon hygristor was used. For pressure measurement, a Honeywell silicon diaphragm barometer was used. To commutate between the temperature, pressure, and humidity sensors and encode the meteorological data measurements, a set of meteorological electronics was developed using commercially available integrated circuits. A special light-weight telemetry transmitter providing an output of 1/2 watt at 400 to 406 megahertz was designed and constructed. Power for the transmitter and minisonde electronics was provided by a small flat disc battery using lithium electrochemical technology. Three minisondes were launched using 30-gram latex balloons and rose to an altitude of greater than 15,000 feet at a rise rate of approximately 600 feet per minute. During the flight, temperature, pressure, and humidity data were successfully telemetered back to an FM receiver located on the ground.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

I. INTRODUCTION

The Navy has a requirement to measure a vertical profile of index of refraction from the surface of the ocean to a height of at least 20,000 feet. It is desirable to make these measurements from many classes of ships. Further, it is desirable to make these measurements under conditions of calm or high winds and from essentially nonmotion to full operational speed.

The purpose of this program was to demonstrate that it is possible to build a light-weight miniature meteorological sonde (minisonde) which can be borne aloft by a 30-gram latex balloon. In many field applications, it is difficult to fill and launch a very large balloon, either because of space limitations or because of high winds or other environmental conditions. It is very useful to have a balloon no larger than 30 inches in diameter so that it can be filled within a room and carried out through a standard door for launching. Calculations show that a 30-gram latex balloon, when inflated to 30 inches in diameter, will lift a minisonde including battery which has a weight of approximately 85 grams at an ascent rate of 1,000 feet per minute. It is now technologically possible to build an 85-gram minisonde that is capable of measuring temperature, pressure, and humidity. During this program, 85-gram minisondes were built and successfully launched with 30-gram balloons.

The program was broken down into two parts - first, the assembly of five minisondes and, second, the launching and data reduction for these minisondes. The construction of a small, light-weight minisonde requires that new miniature sensors and high-efficiency electronics be used. For temperature measurement, the standard rod thermistor was selected. For humidity measurement, the conventional VIZ carbon hygristor was used because of its light weight. For pressure measurement, a Honeywell silicon diaphragm barometer was used. This pressure sensor consists of a small silicon chip with strain-sensitive resistors diffused into the surface. This sensor is mounted on an evacuated tube so that changes in absolute pressure can be measured. To commutate between the temperature, pressure, and humidity sensors and encode the meteorological data measurements, a set of meteorological electronics was developed using commercially available integrated circuits. By the use of integrated circuits, it is possible to achieve all the commutation functions in a small and particularly light-weight package. The sensors are commutated on a time basis, with a complete cycle every 400 milliseconds. At a rise rate of 1,000 feet per minute, this gives a complete set of data every 7 feet of altitude. A special light-weight telemetry transmitter providing an output of 1/2 watt at 400 to 406 megahertz was designed and constructed by the Honeywell Test Instruments Division (TID), Annapolis, Maryland. Power for the transmitter and minisonde electronics was provided by a small flat disc battery constructed by the Honeywell Power Sources Center (PSC) using lithium electrochemical technology. The battery consisted of four Honeywell G3060 cells with an initial voltage of 11.6 volts.

To illustrate the operational capabilities, three minisondes were launched at Honeywell's Annapolis operations during the week of 14 February 1977. These minisondes were launched using 30-gram latex balloons and rose to an altitude of greater than 15,000 feet at a rise rate of approximately 600 feet per minute. During the flight, temperature, pressure, and humidity data were successfully telemetered back to an FM receiver located on the ground.

II. MINISONDE COMPONENTS

A. PRESSURE SENSOR

The silicon diaphragm barometer is an all solid-state pressure transducer. It utilizes a chip of silicon on which strain-sensitive resistors have been diffused. The back of the silicon chip is etched away to leave a thin flexible diaphragm. This chip is mounted on a small evacuated container so that absolute pressure changes can be sensed. As the pressure on the diaphragm changes with barometric pressure changes, the diaphragm flexes and changes the resistance of the diffused strain-sensitive resistors on the surface. This differential pressure is amplified with an external operational amplifier to produce an output signal which is proportional to absolute pressure over a range from 0-1500 millibars. The system is temperature compensated to operate over a range from -50 to +50°C.

Photographs of the silicon diaphragm barometer are shown in Figures 1 and 2. The electronic amplifier and temperature compensation networks are mounted on a thick-film ceramic substrate. The barometer chip can be seen in Figure 1 in the right hand corner. In Figure 2, the vacuum chamber for the barometer is seen in the upper left hand corner. The white spots on the substrate are caused by the automatic computer-controlled trimming of the resistor elements to adjust the span and range of the transducer.

The output signals on the solid-state barometer are linear and ratiometric with power supply voltage as shown in Figure 3. Both the full-scale signal and the null voltage are proportional to power supply voltage. The exact value of barometric pressure can be calculated from the expression in Equation 1:

$$P = \frac{1931}{V_{CC}} (V - 0.087\, V_{CC}) \qquad (1)$$

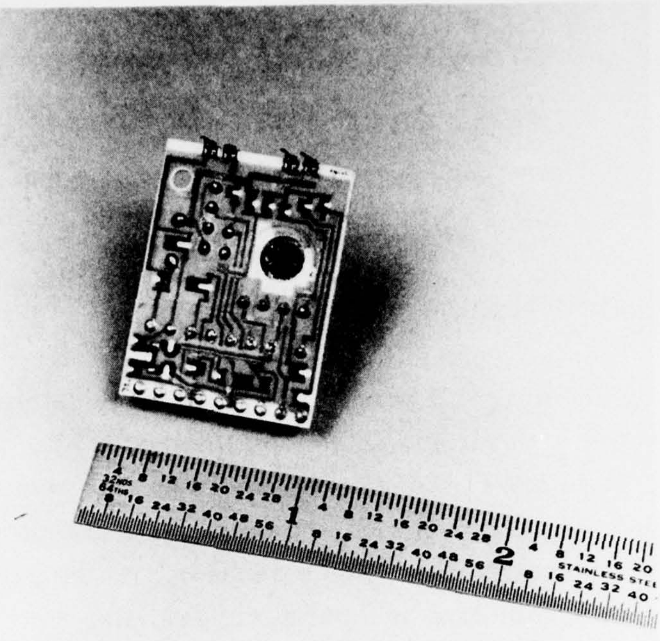


Figure 1. Silicon Diaphragm Barometer Mounted on Ceramic Substrate, Front View

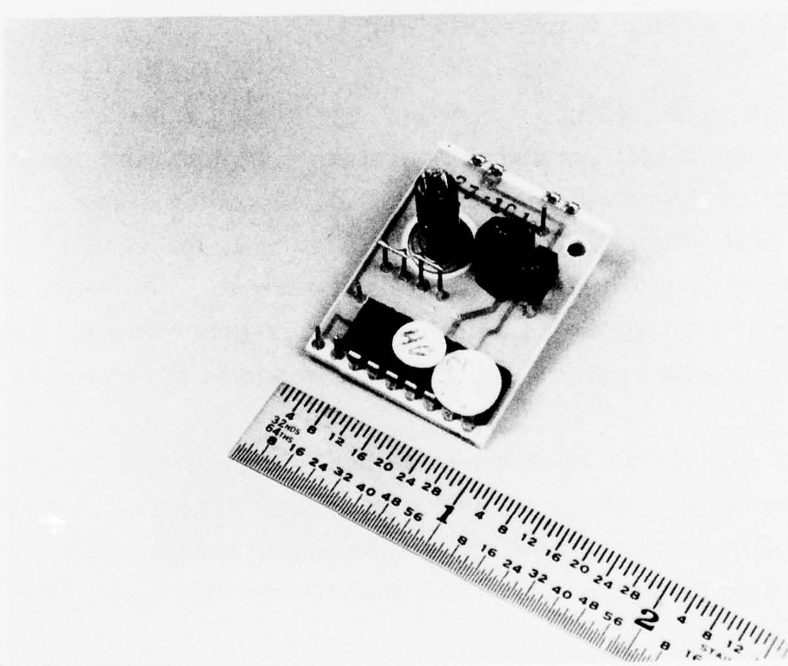


Figure 2. Silicon Diaphragm Barometer Mounted on Ceramic Substrate, Back View

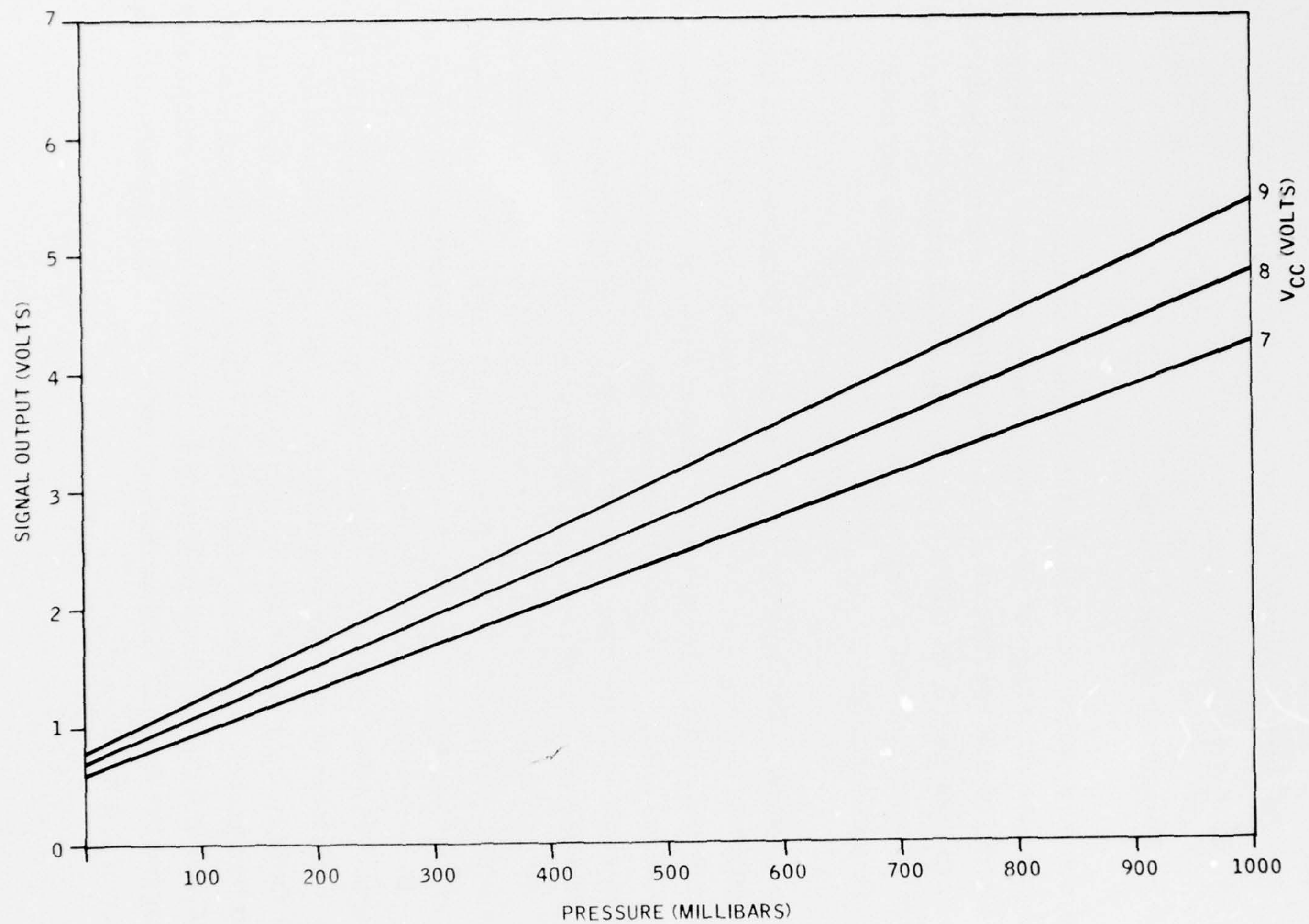


Figure 3. Silicon Diaphragm Barometer Calibration Curve for Supply Voltages of 7-9 Volts

where:

P = Pressure in millibars.

V_{CC} = Supply voltage in volts.

V = Barometer output in volts.

All barometers, as presently manufactured, meet an accuracy of 1 percent of full scale over the full range of pressure and temperature. For barometric units, the sensors are recalibrated. The repeatibility and hysteresis as measured are less than 0.25 millibar. The measured output of five pressure transducer models is shown in Table 1. For the minisonde, our goal is an RMS accuracy of 1 millibar.

The silicon diaphragm barometers are temperature compensated to better than 0.09 millibar per °C. For a typical operating temperature range of +50 to -50°C, this would give a temperature induced error of ±5 millibars over the temperature range. This would indicate that a temperature correction should be introduced in the data reduction period. To determine the thermal lag of the barometer, a sensor and substrate were mounted in a temperature chamber. In the chamber, temperature was lowered at a typical adiabatic lapse rate of 2°C per minute to simulate a typical flight. The temperature lags between the air temperature and substrate temperature are shown in Figure 4. It can be seen that the substrate tracks very closely to free air temperature. In actual operation, the barometer must be shielded to prevent RF pickup within the barometer electronics. In this case, there is an additional thermal lag between the barometer and the free air temperature. A shielded barometer was placed in the temperature chamber and cooled at a rate of 2°C per minute as shown in Figure 5. The temperature compensating element lagged the free air temperature by about 8°C, which would correspond to an error of 0.8 millibar.

Table 1. Measured Output Voltage for Five Silicon Diaphragm Barometers

Pressure (Millibars)	Output Voltage for Silicon Diaphragm Barometer Serial No.				
	1	4	9	10	11
50	1.015	1.014	0.987	1.003	0.973
100	1.254	1.252	1.208	1.242	1.220
150	1.495	1.492	1.433	1.482	1.449
200	1.736	1.730	1.659	1.722	1.679
250	1.976	1.969	1.887	1.962	1.909
300	2.216	2.208	2.115	2.202	2.141
350	2.456	2.445	2.345	2.442	2.373
400	2.694	2.682	2.576	2.680	2.606
450	2.931	2.919	2.808	2.918	2.839
500	3.166	3.154	3.041	3.154	3.072
550	3.400	3.388	3.276	3.389	3.306
600	3.632	3.620	3.510	3.621	3.540
650	3.862	3.852	3.747	3.853	3.775
700	4.091	4.082	3.934	4.083	4.010
750	4.317	4.310	4.222	4.310	4.243
800	4.541	4.537	4.460	4.536	4.478
850	4.763	4.762	4.700	4.760	4.713
900	4.983	4.985	4.740	4.980	4.947
950	5.201	5.207	5.182	5.200	5.182
1000	5.416	5.426	5.422	5.416	5.415
1050	5.633	5.649	5.669	5.636	5.654

Input = 9.000 ± 0.001 VDC

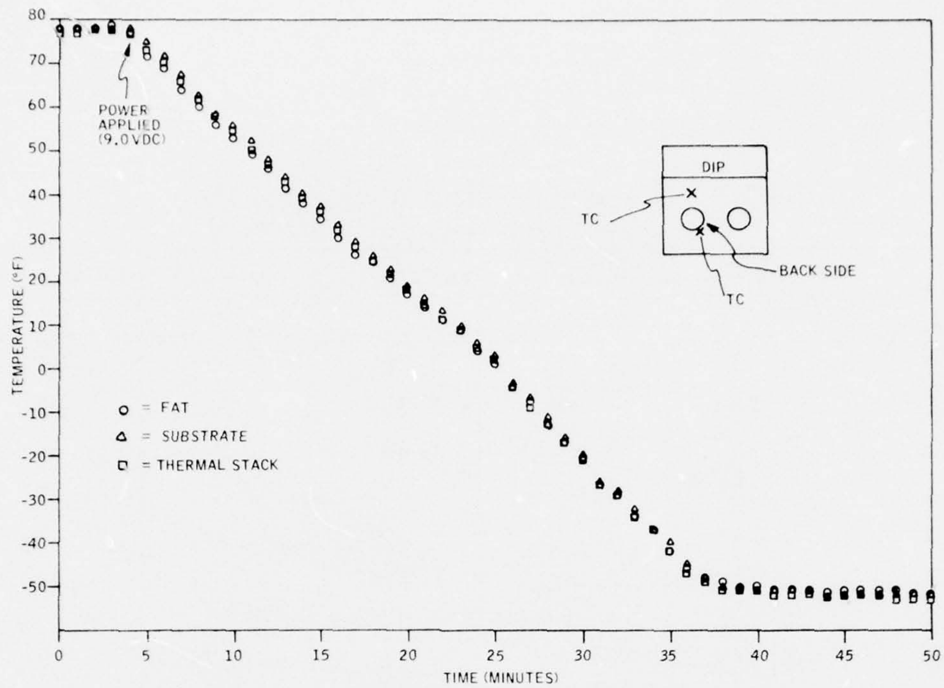


Figure 4. Performance of Unshielded Silicon Diaphragm Barometer

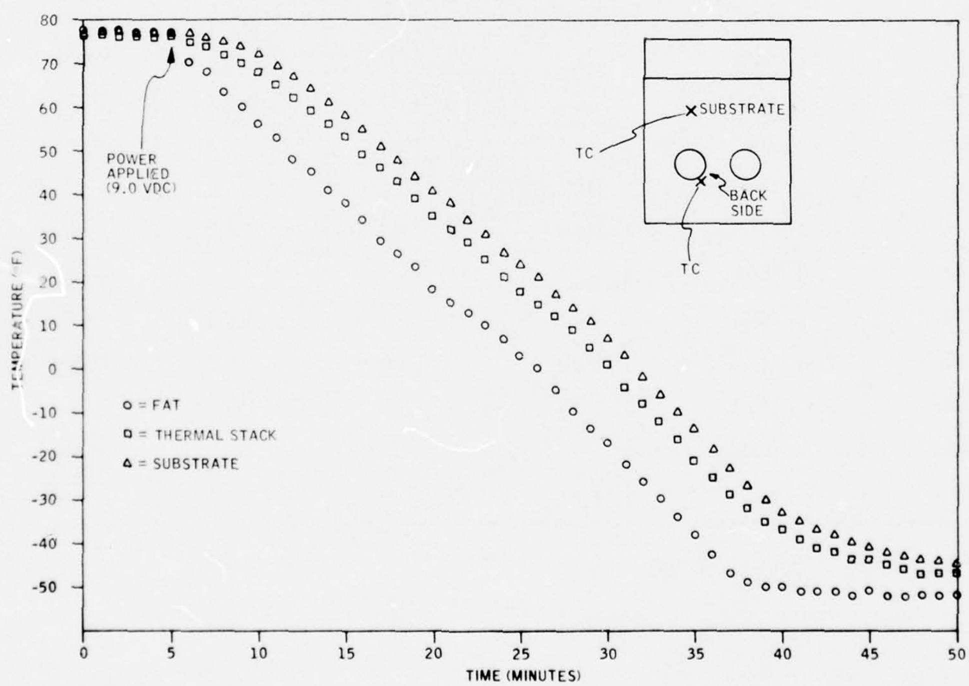


Figure 5. Performance of Shielded Silicon Diaphragm Barometer

This error is small enough that the measured free air temperature can be used to correct the temperature lag. If a more exact compensation is desired, correction for a single time constant lag can also be introduced in the data processing.

To convert from pressure to altitude, the barometer equation shown in Equation 2 is used:

$$H = \frac{T_o R}{n} \left[\left(\frac{P_L}{P_o} \right)^n - \left(\frac{P}{P_o} \right)^n \right] \tag{2}$$

where:

n	=	0.21 for dry air.
n	$\simeq$	0.19 for typical atmosphere at 15°C.
T_o	=	Temperature at sea level in = 518°K.
R	=	53.35 feet per °K.
P_o	=	Sea level pressure in 1013 millibars.
P	=	Pressure at minisonde altitude.
P_L	=	Launch pressure.
H	=	Height (altitude) in feet.

Substituting in Equation 2 for a sea level temperature of 15°C and a sea level pressure of 1013 millibars, we get Equation 3:

$$H = 145000 \left[\left(\frac{P_L}{1013} \right)^{0.19} - \left(\frac{P}{1013} \right)^{0.19} \right] \tag{3}$$

Reducing this equation, we get an expression for altitude versus pressure in more usable form, as shown in Equation 4:

$$H = 39100\,(P_L^{\,0.19} - p^{\,0.19}) \qquad (4)$$

B. TEMPERATURE AND HUMIDITY SENSORS

For temperature sensing, a white-painted rod thermistor (VIZ Model 1162-230) was used with temperature characteristics as shown in Table 2.

Table 2. Temperature Versus Thermistor Resistance Ratio

Temperature (°C)	Ratio
+40	0.798
+30	1.000
+20	1.270
+10	1.635
0	2.139
-10	2.847
-20	3.859
-30	5.341
-40	7.561
-50	10.97
-60	16.37
-70	25.17
-80	40.04
-90	66.07

Each thermistor is furnished with a lock-in resistance calibration at 30°C. The resistance ratio in Table 2 represents the ratio of actual thermistor resistance at any temperature T compared with the resistance at 30°C. The lock-in resistance is normally 14,000 ohms. The resistance ratio versus temperature expression can be expressed more exactly as shown in Equation 5:

$$r = 3.379\,(10)^{-4}\ e^{\left[\frac{1}{273.2 + T} - 32.65\left(\frac{1}{273.2 + T}\right)^{2}\right]\,2715.6} \qquad (5)$$

where:

r = Ratio of resistance at temperature T to resistance at 30°C.

T = Air temperature in °K.

By solving Equation 5 for temperature, a more useful form of the thermistor equation is derived, as shown in Equation 6:

$$T = \sqrt{\left[\frac{240.5}{A} - (273.2)^2 + B^2\right]} - B \qquad (6)$$

$$A = \ln\left(\frac{r}{3.379\,(10)^{-4}}\right)^{1/2715.6}$$

$$B = \frac{546.32\,A - 1}{2A}$$

The desired accuracy of temperature measurement is 0.1°C.

A carbon hygristor manufactured by VIZ was used for humidity sensing (VIZ, Model 1163-50). Each hygristor is furnished with a lock-in resistance calibration value at 33 percent relative humidity. Using the ratio of measured resistance to lock-in resistance, the humidity can be determined from Table 3. The desired accuracy of humidity measurement is 5 percent relative humidity.

The humidity element has a 250,000-ohm ±1 percent resistor connected in parallel and a 7,100-ohm ±1 percent resistor connected in series with the above parallel combination. This configuration provides a humidity input

Table 3. Ratio of Resistance at Given Relative Humidity and Temperature to that at 33 Percent Relative Humidity and 25°C

Relative Humidity (Percent)	Ratio of Resistance and Temperature			
	+40° C	+25° C	0° C	-40° C
10	0.61	0.585	0.55	0.52
15	0.72	0.695	0.65	0.62
20	0.82	0.800	0.78	0.74
25	0.89	0.875	0.85	0.82
30	0.95	0.940	0.92	0.90
33	1.00	1.00	1.00	1.00
35	1.04	1.05	1.06	1.10
40	1.15	1.175	1.23	1.3
45	1.27	1.32	1.40	1.63
50	1.47	1.58	1.75	2.23
55	1.85	2.00	2.35	3.1
60	2.3	2.50	3.1	4.2
65	3.	3.25	4.1	6.5
70	4.	4.5	6.	10.2
75	6.4	7.3	9.8	17.
80	10.	12.	17.	29.
85	16.	18.5	26.	---
90	23.	29.	44.	---
95	40.	60.	86.	---
100	126.	140.	170.	---

resistance of 257,100 ohms with an open humidity element and 7,100 ohms with a shorted humidity element. Both the 250,000-ohm and 7,100-ohm resistors have a temperature coefficient of ±100 parts per million.

The hygristor is mounted in low-mass metal spring clips to minimize the obstruction in air flow. It is desirable to have a hygristor mounted in such a way as to see the free air temperature and humidity.

To determine humidity, it is necessary to determine the resistance of the hygristor separately from the humidity resistance network. The resistance of the hygristor can be determined from Equation 7:

$$R_h = \frac{(R-7.1)\ 250}{250 - (R-7.1)} \tag{7}$$

where:

R = Network resistance.

R_h = Resistance of hygristor in K ohms (ohms x 10^3)

From this resistance and the lock-in value, humidity can be determined from Table 3.

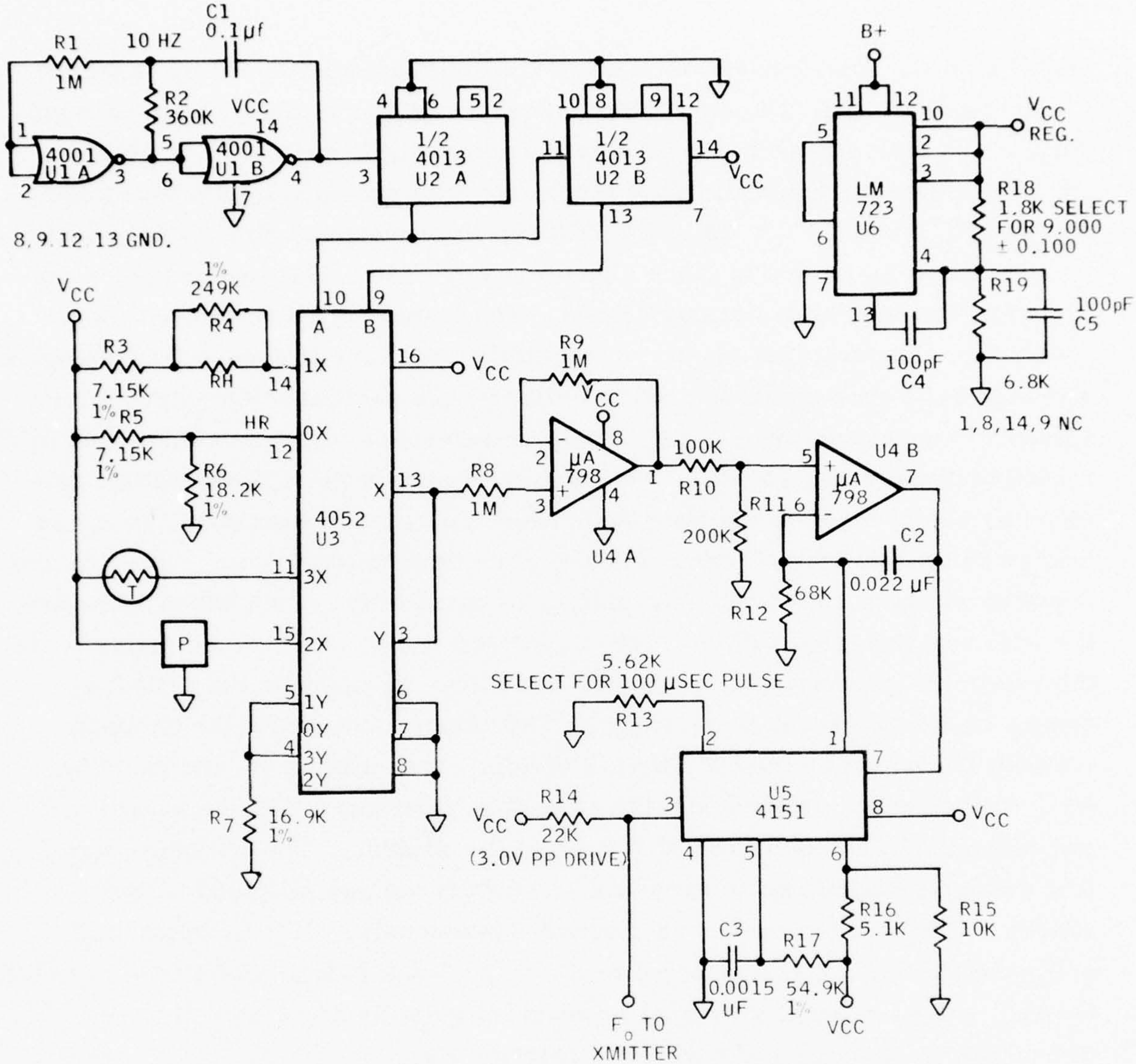
C. METEOROLOGICAL ELECTRONICS

A meteorological sonde is used to measure the temperature, pressure, and humidity profile of the atmosphere. To do this, a sonde must have three parts – the sensors which measure the meteorological environment and a set of meteorological electronics which serves as the brain to transfer these data through a transmitter, which is the third part of the sonde, the voice.

The meteorological electronics serve two main functions; the first is to commutate or switch between the sensors in sequence. The second function is to take the voltage readout of the sensors and encode these data as a frequency so that it can be telemetered back to the ground. Figure 6 shows a complete circuit diagram of the minisonde meteorological electronics. The two functions can be observed from this diagram. The commutating or switching function is provided by integrated circuits U1, U2, and U3. U1 is a CMOS logic circuit connected as a 10-hertz oscillator which serves as a clock ticking at a 0.1-second rate. This clock drives a flip flop (U2) which converts the clock to a switching signal to operate the solid-state switch (U3). The solid-state switch connects each of the sensors in turn through the voltage-to-frequency converter part of the circuit. The encoding function is provided by semiconductors U4 and U5. U4A serves as a buffer for the voltage signal from the sensors. U4B is a voltage-tuned current source used to operate the voltage-to-frequency converter stage (U5). U5 provides an output frequency in the 0-2,000 hertz frequency range that is linearly proportional to the voltage signal from the sensors. The output voltage from the sensors is restricted so that the modulating frequencies do not exceed a range of 200-2,000 hertz.

The voltage encoding oscillator has essentially instantaneous response to changes in sensor output. The voltage-controlled oscillator (VCO), serving as a voltage-to-frequency converter, will respond to the input drive voltage from the sensors on a cycle-by-cycle basis; i.e., it is able to respond to a change in sensor output within 1/1,000 of 1 second or less. The effective response time of the system is limited primarily by the speed of response of the sensors and the clock commutation frequency. The 0.1-second commutation rate gives an output from all sensors every 0.4 of 1 second, which is equivalent to about every 7 feet of vertical ascent.

Going through the circuit now in more detail to describe the total circuit operation, U1 is one-half of a CMOS NOR gate connected as a monostable



4052 COMMAND SEQUENCE

	10	9	
1 HR	0	0	0X, 0Y
2 T	1	1	3X, 3Y
3 P	0	1	2X, 2Y
4 RH	1	0	1X, 1Y

NOTES:

1. ALL RESISTORS = 1/8W 5% UNLESS SPECIFIED.
2. ALL CAPACITORS = CK05
3. ALL INTEGRATED CIRCUITS = PLASTIC

Figure 6. Meteorological Electronics Circuit Diagram

multivibrator. Its 10-hertz oscillation frequency is determined by capacitor C1 and resistor R2. The oscillation frequency is nearly independent of supply voltage and temperature. To operate the commutator switch U3, a binary counting signal is required. This binary count is provided by the two-stage flip flop (U2A and U2B). U2 is a CMOS flip flop connected as a serial counter to count down the 10-hertz clock signals and provide a 1/10-second commutating signal to the solid-state switch U3. The commutation sequence is high reference, temperature, pressure, humidity, and back to high reference again. The high reference signal is used to calibrate the oscillator and correct for changes in supply voltage (V_{CC}). The high reference signal is established by the resistive divider (R5 and R6). The high reference is the highest voltage provided by any of the sensors over their expected range of operation, so it can always be used to identify the beginning of a commutation cycle. The relative humidity element, the carbon hygristor, is paralleled by 249,000-ohm resistor (R4) and in series with a 7,150-ohm resistor (R3). These elements limit the maximum excursion of the sensor rssistance to maintain the VCO frequency in the 200-2,000 hertz range. The output signal from the humidity element is formed by the top network divider connecting to 1X and resistor R7. To select the relative humidity reading, terminal 1X is connected to X and terminal 1Y is connected to Y to form the divider. The pressure signal is a voltage proportional to pressure and supply voltage provided by the silicon diaphragm barometer as discussed previously. To commutate the pressure signal, 2X is connected to X on U3. No additional reference resistor is used. The temperature signal is provided by a divider formed by the thermistor resistance and reference resistor R7.

The commutation switching is provided by a CMOS 4052 switch shown as U3 in the diagram of Figure 6. This is a four-pole double-throw switch commutated by the binary signal from flip flop U2.

The output voltage from the commutator is buffered by the unity-gain-connected operational amplifier (U4A). A resistive divider consisting of resistors R10 and R11 attenuate the input voltage signal by one-third to maintain the voltage-to-frequency converter in its most linear region. The VCO operates best when the input signals are less than half of the supply voltage V_{CC}. The operational amplifier U4B serves as a voltage variable current source to provide a more linear transfer function from VCO U5. The VCO is a 4151 integrated circuit VCO. Its output is a pulse with a variable repetition rate proportional to input voltage. The pulse width is set at 100 microseconds, which is determined by the value of resistor R13. A 3-volt peak-to-peak signal fully modulates the transmitter. The output level can be adjusted with resistor R14.

To stabilize circuit operation, an LM 723 integrated circuit power supply regulator is used (shown as U6). Resistor R18 was selected to obtain an output voltage of 9 volts.

So that the meteorologic data can be telemetered down to the ground, it is necessary to encode the voltage signals from each of the sensors. The simplest method, and the one generally used for metsondes, is to convert the voltage signal to a frequency which can then be decoded on the ground to obtain voltage again. The data encoding, as shown in Figure 6, is accomplished with a VCO, or voltage-to-frequency converter, using a 4151 integrated circuit (U5). To obtain accurate encoding and decoding of the data, it is necessary to know the transfer function of the VCO very accurately. It is not necessary that the VCO be linear, only that the characteristic be known. In the case of the 4151 integrated circuit VCO, it is very nearly linear by itself, with maximum deviations of 0.3 percent. This deviation from linearity will be corrected in the processor by adding a second-order correction to the transfer equation.

It is not necessary that a VCO be accurate; i.e., it is not essential that the output frequency of all units be the same for the same voltage. It is, however, necessary that they be reproducible. Any change in the slope of the

VCO or its gain can be compensated by the use of a known reference voltage, which, in this case, is called the high reference. The high reference is thus able to compensate for changes in sensor output due to changes in supply voltage V_{CC} as well as correcting for changes in amplifier gain or changes in oscillator slope or sensitivity. The 4151 integrated circuit VCO has an output that is 0 in frequency with 0 input voltage. That means that the scope is nearly a straight line described by Y = mX. Thus, the slope m can be defined if one value is known such as the high reference. Since the accuracy of the total measurement is dependent on the definition of the transfer function for the VCO, this transfer function was measured for a variety of conditions. The VCO output was measured over the total voltage range, over the supply voltage range, over the total temperature range, and was even measured for five different 4151 integrated circuit VCO. Figures 7 and 8 show the voltage transfer function of a typical 4151 integrated circuit VCO. Figure 8 is over a reduced range of voltage to illustrate the nonlinearity below 1 volt. Because of the linearity of this oscillator, it is difficult to visualize the deviation from linearity. To better illustrate this deviation, the successive plots show only a variation from a straight-line fit. Although the nonlinearities are much less than 1 percent, they are now readily visible, as shown in Figures 9 - 13. In these figures, the power supply voltage was changed from 13. 6 volts down to 10 volts to illustrate the effect on transfer function. It can be seen that, with the regulator used, there is no significant change in the transfer characteristic of the VCO. Figure 11 shows the first 1. 5 volts of the curve in more detail to better illustrate the deviation from linearity in this region. It can be seen that there are two characteristics; one below 1. 5 volts and the other in region zones 1. 5 to 6. 0 volts. The curve is locked in at 6. 0 volts by the high reference.

To illustrate the effect of temperature on the VCO transfer function, one of the integrated circuits was measured over the temperature range from -20 to +70°C, as shown in Figures 14-18. As can be seen, the temperature does not

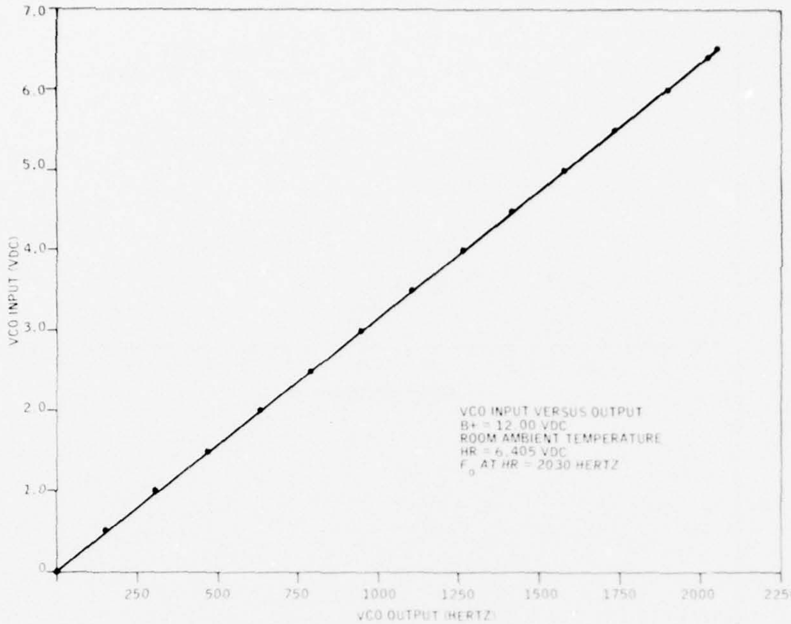


Figure 7. Voltage Transfer Function, Typical 4151 Integrated Circuit VCO (F_o at High Reference = 2030 Hertz)

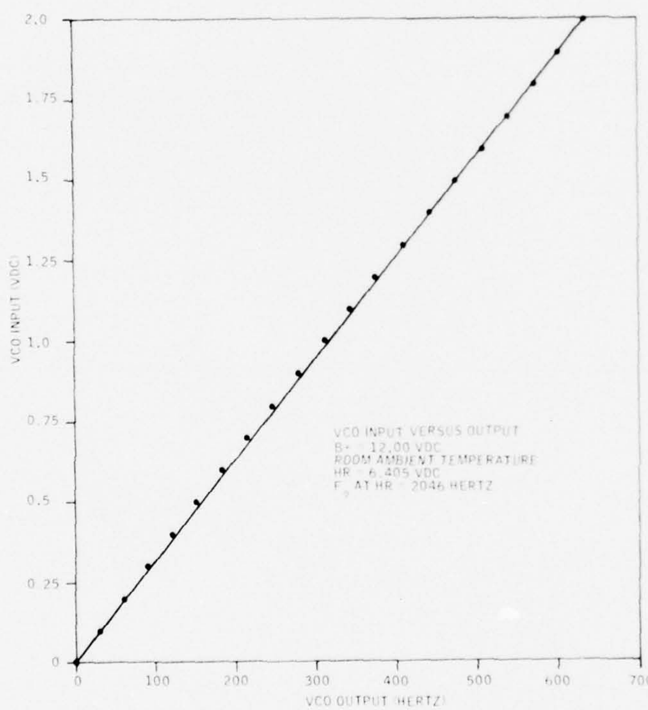


Figure 8. Voltage Transfer Function, Typical 4151 Integrated Circuit VCO (F_o at High Reference = 2046 Hertz)

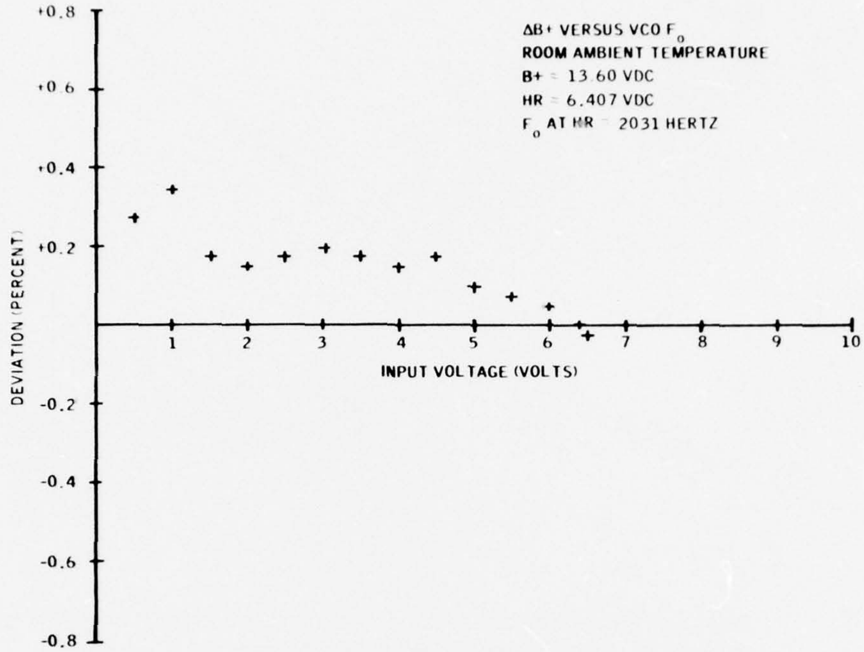


Figure 9. ΔB+ Versus VCO F_o (B+ = 13.60 VDC)

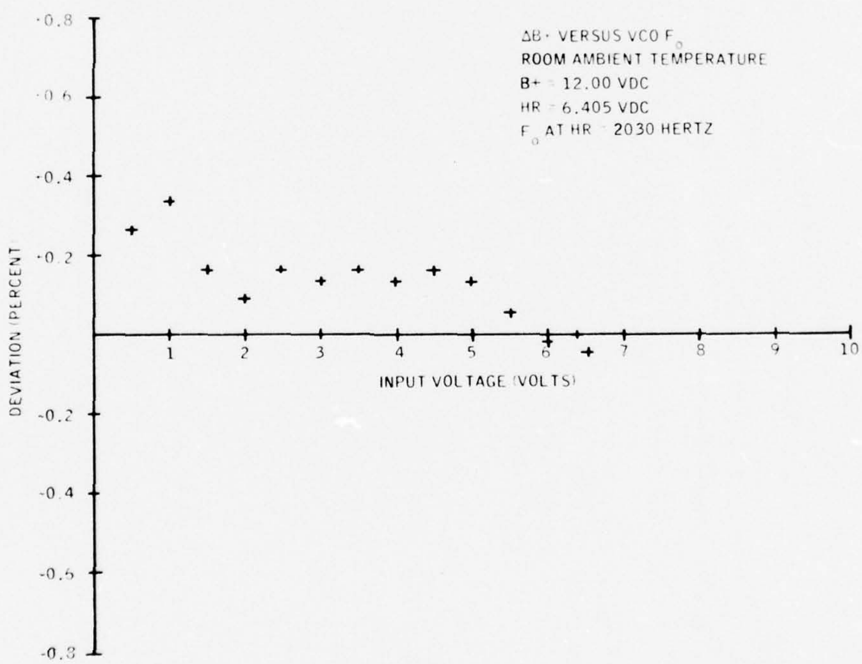


Figure 10. ΔB+ Versus VCO F_o (B+ = 12.00 VDC)

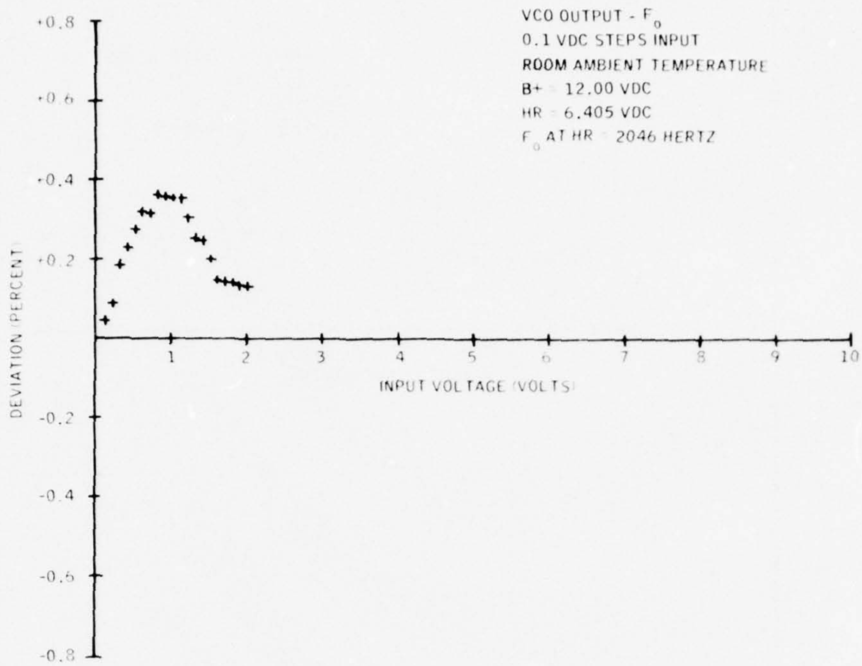


Figure 11. VCO Output Versus VCO F_o, 0.1 VDC Steps Input (B+ = 12.00 VDC)

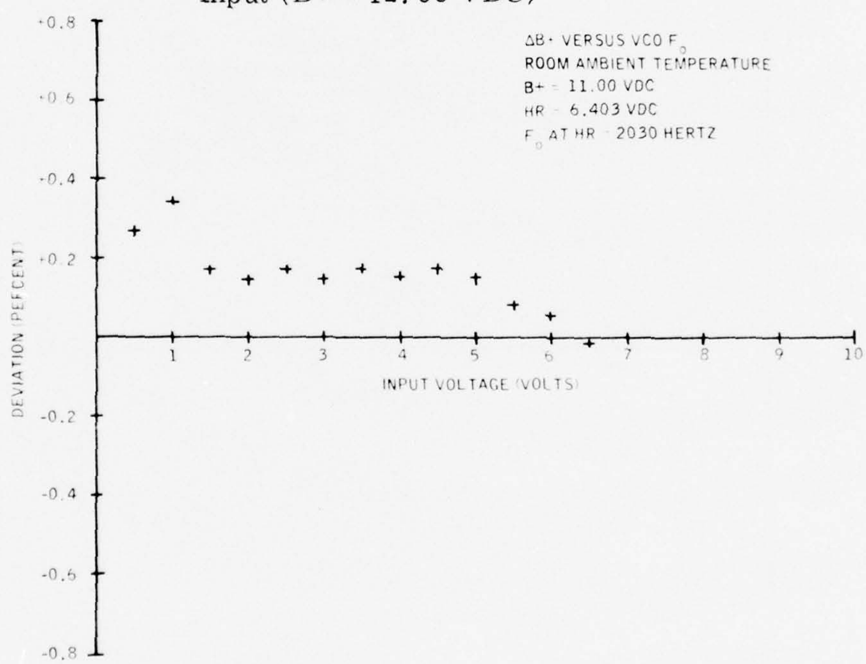


Figure 12. ΔB+ Versus VCO F_o (B+ = 11.00 VDC)

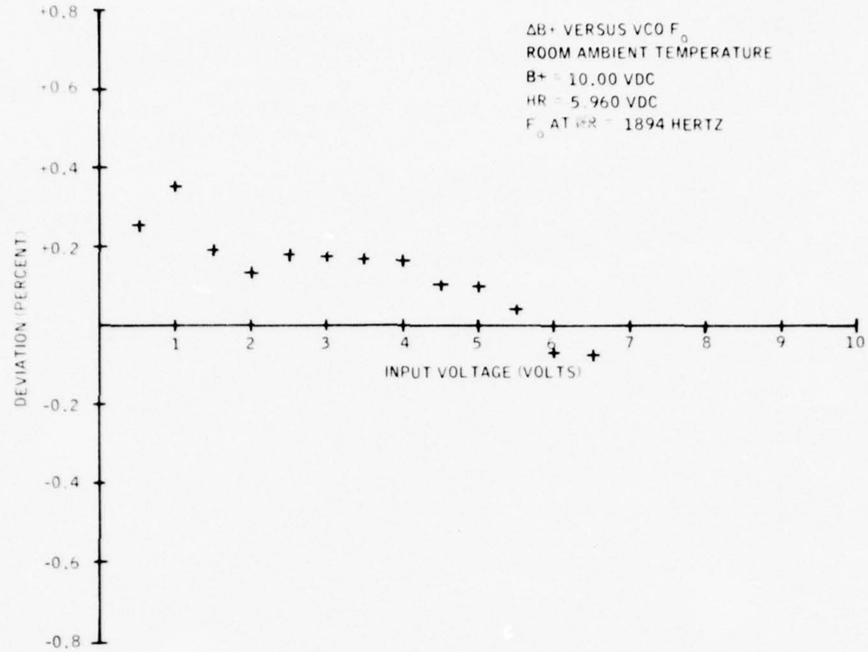


Figure 13. ΔB+ Versus VCO F_O (B+ = 10.00 VDC)

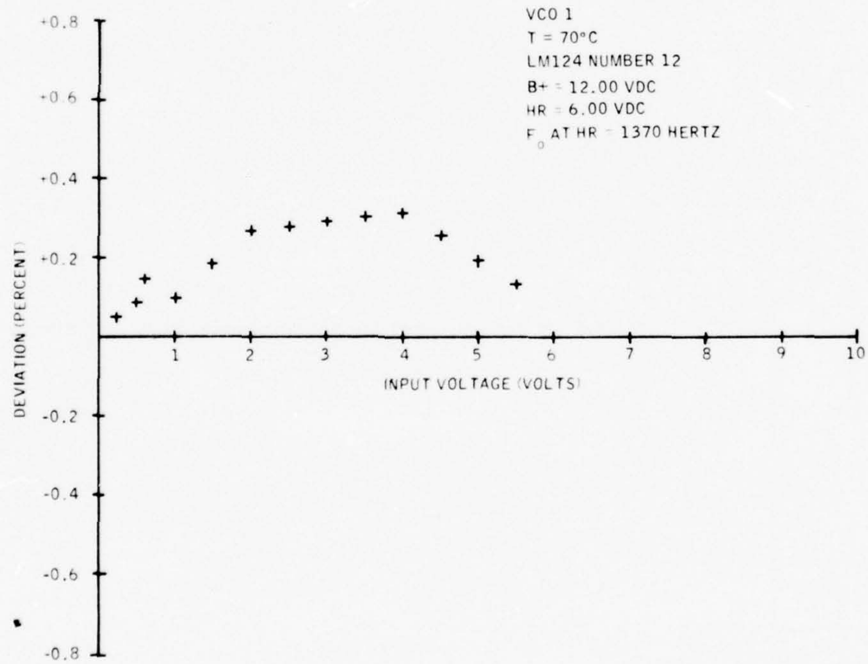


Figure 14. VCO-1, T= +70°C, F_O at High Reference = 1370 Hertz

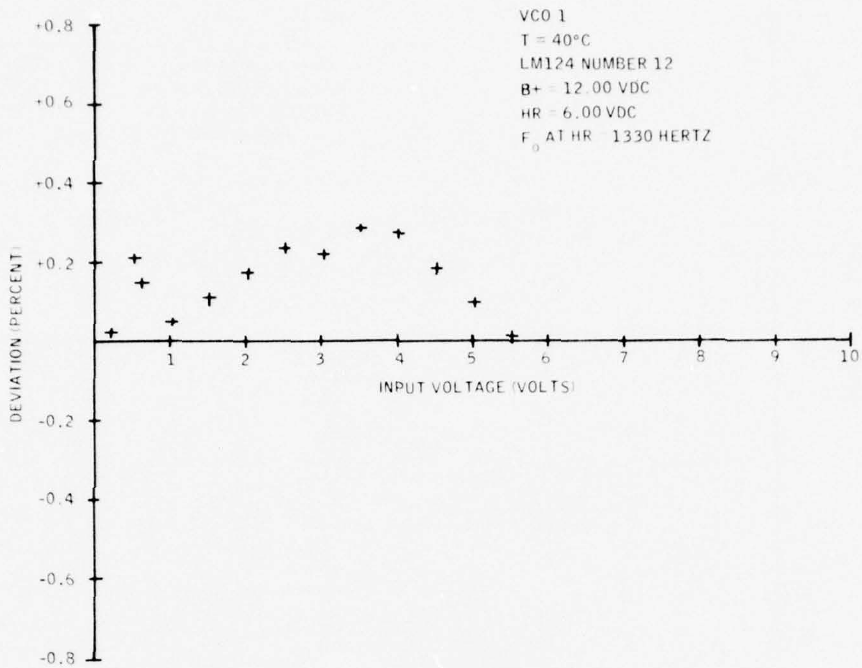


Figure 15. VCO-1, T= +40°C, F_O at High Reference = 1330 Hertz

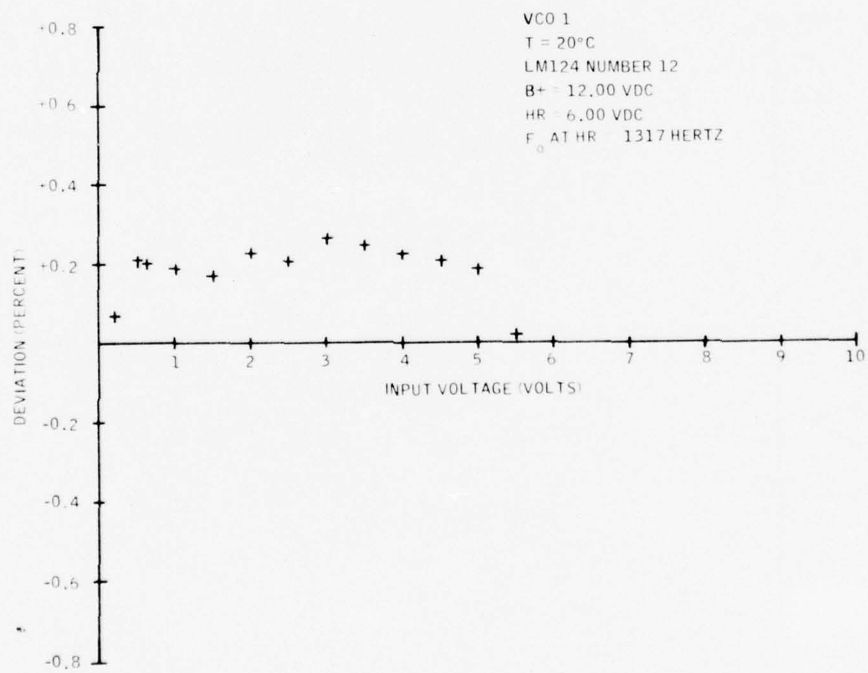


Figure 16. VCO-1, T= +20°C, F_O at High Reference = 1317 Hertz

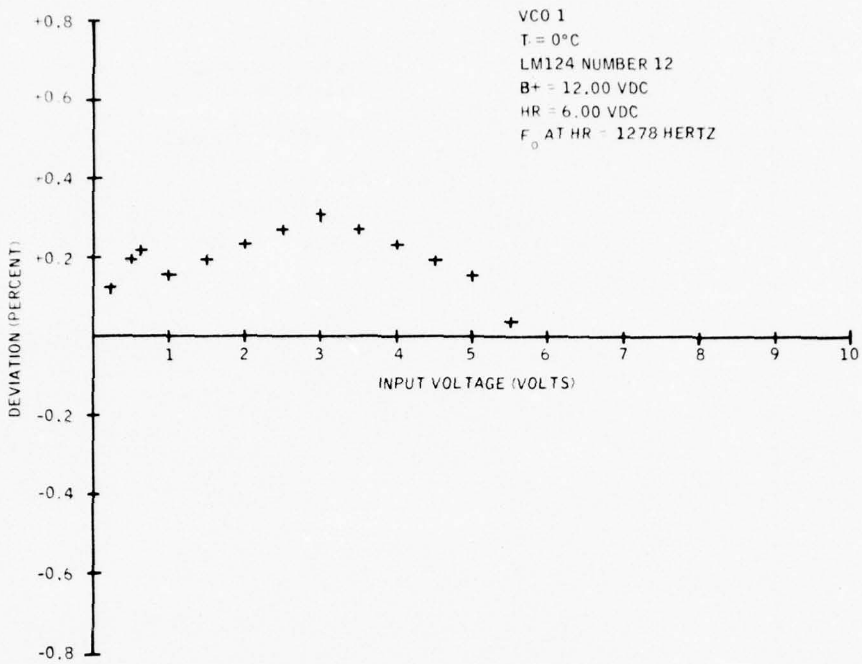


Figure 17. VCO-1, T= 0°C, F_O at High Reference = 1278 Hertz

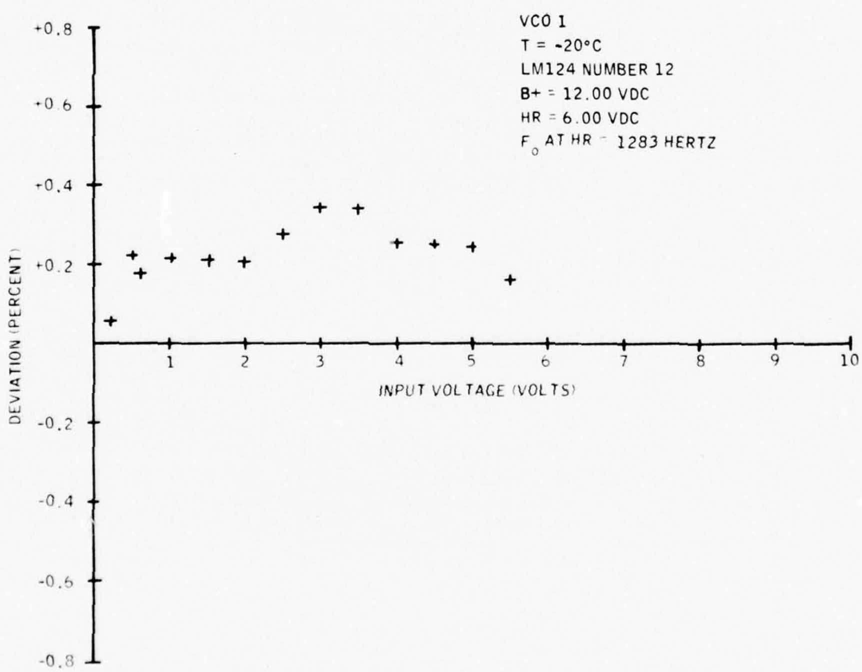


Figure 18. VCO-1, T= -20°C, F_O at High Reference = 1283 Hertz

have a significant effect on the transfer function or the VCO linearity correction curve. These measurements versus temperature are typical of the performance that can be expected of the 4151 integrated circuit VCO. Four additional units were measured, as shown by the data in Appendix A. To determine the effect of the current source U4B on the VCO linearity, the transfer function was measured using four different LM 124's, as shown in Appendix A. The LM 124 has no significant effect on the calibration curve.

D. TELEMETRY TRANSMITTER

Since the meteorological information is being remotely sensed, it is necessary to transfer this information to the ground. A telemetry transmitter is used to telemeter the meteorological sensored data to a receiver and processor located on the ground. The transmitter must be small and particularly lightweight so that it can be launched with a 30-gram balloon. In addition, the transmitter must be very efficient so that a minimum amount of battery weight is required to power the transmitter. The transmitter design is a 0.5-watt FM transmitter operating in the 400-406 megahertz range. The transmitter is frequency modulated with a pulsed signal of 100-microsecond wide pulses with a repetition rate of 200-2,000 hertz. The telemetry transmitter should have sufficient power to operate over a telemetry range of 25 miles and provide sufficient signal strength that it can be received by a telemetry receiver operating in a typical high electromagnetic interference environment on shipboard.

The goal of the transmitter development was to design a transmitter to replace the conventional single transistor power oscillator type transmitter while reducing the weight and size of the transmitter by approximately 70 percent and improving its electrical characteristics. The transmitter design and construction was performed by Honeywell's Annapolis operations.

1. Telemetry Transmitter Specifications

The specifications for the telemetry transmitter are shown in Table 4.

Table 4. Specifications for Telemetry Transmitter

Center Frequency (F_o)	400 to 406 megahertz
Frequency Drift	1 megahertz
Power Out	0.5 watt (+27 decibels referred to 1 milliwatt)
Operational Voltage	+13.5 VDC to +10 VDC
Battery Drain	120 milliamperes maximum
Antenna Gain	0 decibels
Weight	15 grams
Modulation	FM
Operational Temperature	-50°C to +50°C

Six models of the transmitter were constructed and tested, with the results as tabulated in Table 5. It can be seen that the transmitters operate well over the entire frequency range of -50 to +50°C and over the total supply voltage range. There is no power supply regulation required to maintain stable output frequencies from this transmitter. The performance of the transmitters meet the specifications as listed in Table 4.

Table 5. Telemetry Transmitter Test Data

Serial Number	Temperature (°C)	Battery Voltage (Volts)	Current (Milli-amperes)	Frequency (Megahertz)	Power Out (Decibels Referred to 1 Milliwatt)
1	+25	+13.5	112	403.9	+27.0
	+25	+10.0	86	403.6	+24.6
	-50	+13.5	101	404.3	+26.0
	-50	+10.0		404.1	+24.0
	+50	+13.5	119	404.0	+27.5
	+50	+10.0		403.6	+25.0
2	+25	+13.5	114	403.2	+27.0
	+25	+10.0	84	402.9	+25.0
	-50	+13.5		403.1	+28.0
	-50	+10.0		402.9	+26.5
	+50	+13.5		403.2	+27.0
	+50	+10.0		402.9	+25.0
3	+25	+13.5	86	403.0	+26.4
	+25	+10.0	66	402.7	+24.0
	-50	+13.5		403.1	+27.1
	-50	+10.0		402.8	+24.0
	+50	+13.5		403.0	+26.4
	+50	+10.0		402.7	+24.0
4	+25	+13.5	121	403.1	+27.3
	+25	+10.0	94	402.7	+25.0
	-50	+13.5	125	403.1	+27.5
	-50	+10.0		402.8	+25.6
	+50	+13.5	120	403.1	+27.1
	+50	+10.0		402.7	+24.5
5	+25	+13.5	118.5	402.8	+28.0
	+25	+10.0	93	402.7	+25.8
	-50	+13.5	122	402.9	+28.2
	-50	+10.0		402.8	+26.7
6	+25	+13.5	115	403.5	+27.0
	+25	+10.0	89	403.2	+24.6
	-50	+13.5	119	403.9	+27.4
	-50	+10.0		403.6	+25.8
	+50	+13.5		403.5	+26.9
	+50	+10.0		403.2	+24.5

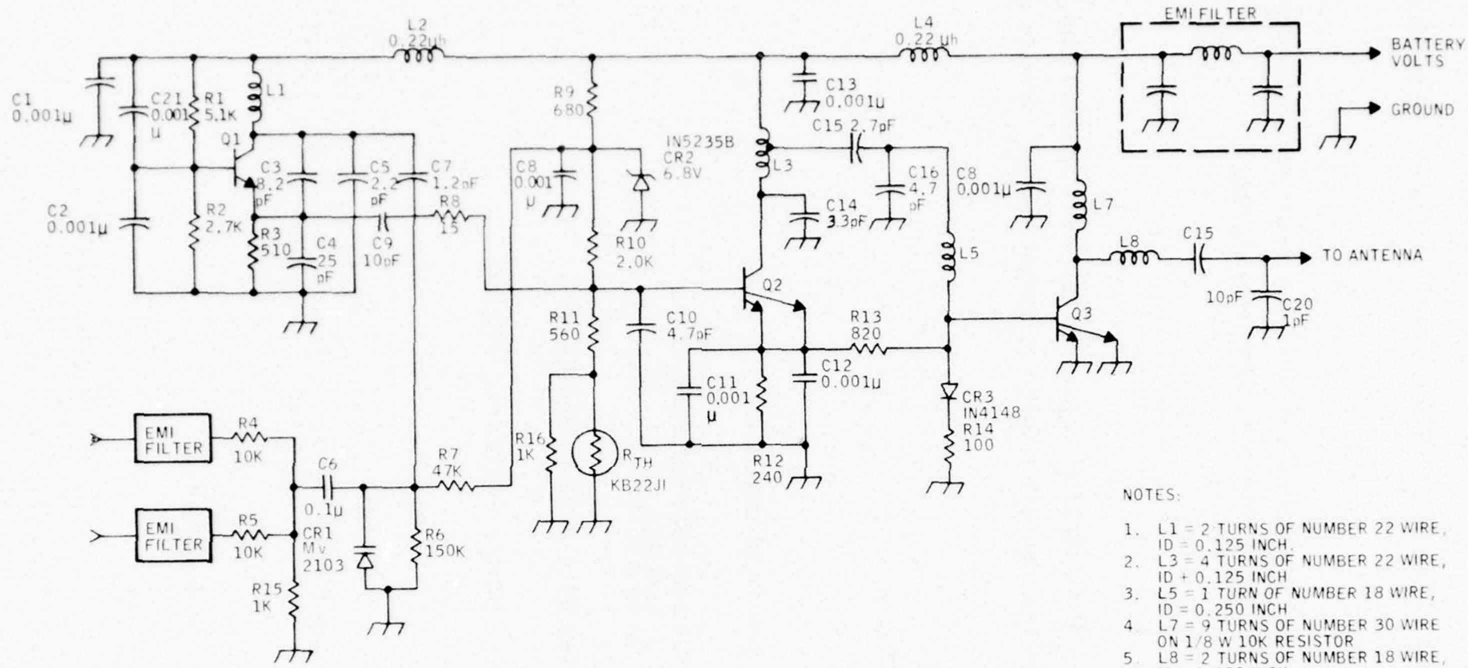
2. *General Description*

a. Mechanical -- The overall size of the complete transmitter unit is 2.25 inches in length, 1.0 inch in width, and 0.5 inch in height. Requirements for ease of packaging made the selection of the antenna of particular importance. The antenna was to be light in weight, durable, capable of being folded in shipment and storage, and then, when released for operational use, become an effective isotropic radiator. The material used was an 0.1-inch-wide strip of blue-tempered steel, 7.75 inches in length. This material had the resiliency and electrical properties required.

b. Electrical -- The required output power delivered to the antenna was 0.5 watt with a fully charged battery. The design effort was to deliver a minimum of 0.5 watt degraded by a maximum 3 decibels over temperature and battery life. While maintaining the required power out, the unit was to remain frequency stable. The transmitter guards against any external RF signals which may cause interference with either the modulation or RF characteristics by employing an RF shield around the entire package.

c. Technical Approach -- An initial goal for frequency stability was not to exceed a total frequency drift of 1 megahertz regardless of temperature or battery voltage. A diagram of the transmitter circuit is shown in Figure 19. The basic concept of using three stages of active circuitry was selected to ensure that frequency stability would be maintained. The intermediate stage between the oscillator and power amplifier gave good buffering action, isolating the antenna and power amplifier from the oscillator.

The unique biasing of the power amplifier requires only a small regulation current through the resistive divider network biasing the intermediate buffer. The biasing network also changes the bias current to the power amplifier to



NOTES:

1. L1 = 2 TURNS OF NUMBER 22 WIRE, ID = 0.125 INCH.
2. L3 = 4 TURNS OF NUMBER 22 WIRE, ID + 0.125 INCH
3. L5 = 1 TURN OF NUMBER 18 WIRE, ID = 0.250 INCH
4. L7 = 9 TURNS OF NUMBER 30 WIRE ON 1/8 W 10K RESISTOR
5. L8 = 2 TURNS OF NUMBER 18 WIRE, ID = 0.250 INCH
6. Q1 NEC 73433
   Q2 NEC 73435
   Q3 CTC C1-12

Figure 19. Telemetry Transmitter Circuit Diagram (403 Megahertz)

compensate for temperature variations. The power out never changes more than 1 decibel over temperature.

Frequency modulation is implemented by the use of a varactor which controls the deviation by the amplitude of the input modulating signal.

3. Telemetry Range

To determine the received RF telemetry signal level, the received signal level P_R is subtracted from the receiver noise threshold P_{RT}. Power at the receiver is given by:

$$P_R = P_T - \alpha + G_A \tag{8}$$

where:

P_R = Receiver power in decibels.

α = Path attenuation between isotropic radiators in decibels.

G_A = Receiver antenna gain in decibels.

P_T = Transmitted power watts in decibels.

Path attenuation α is:

$$\alpha = 36.6 + 20 \log f + 20 \log d \tag{9}$$

where:

f = Frequency in megahertz.

d = Distance in miles.

For a telemetry range of 25 miles and a frequency of 403 megahertz:

$$\alpha = 36.6 + 20 \log 403 + 20 \log 25$$

$$= 36.6 + 52.1 + 28$$

$$= 117\text{-decibel path attenuation.}$$

Assuming the transmitting antenna has a gain of 0 decibels, the radiated power is 316 milliwatts or -5 decibels. A dipole antenna has a gain of 6 decibels. The received power will be $P_R = -5 - 117 + 6 = -116$ decibels.

The noise threshold of a receiver is:

$$P_{RT} = P_N + 10 \log BW + NF \tag{10}$$

where:

P_{RT} = Receiver noise threshold.

P_N = Thermal noise limit = -204 decibels per hertz.

BW = System noise bandwidth.

NF = Receiver noise figure

Thermal noise power in a 1-hertz bandwidth is -204 decibels. Assuming a receiver with a 100-kilohertz IF bandwidth, the noise level is increased by 50 decibels because of the increased noise bandwidth. A typical FM telemetry receiver has a noise figure of less than 6 decibels.

Noise threshold of the receiver is $P_{RT} = -204 + 50 + 6 = -148$ decibels. Thus, the received signal will be -116 decibels, while the receiver noise threshold will be -148 decibels, which gives a signal-to-noise ratio $(P_R - P_{RT})$ of 32 decibels at the maximum telemetry range of 25 miles. This will provide an adequate signal margin to minimize interference from near by RF sources such as radar or other communication equipment.

This sensitivity is based on the use of a dipole receiving antenna which, although low in gain, has the advantage of a wide antenna beam angle. In operation, it only needs to be aimed broadside to the direction of the minisonde ascent.

4. Recommendations and Conclusions

By examining the data, it can be seen that the greatest frequency drift over temperature is 0.7 megahertz and the median frequency drift is approximately 0.4 megahertz. After the transmitter units were packaged with their RF shield and antenna connected, the frequencies of the units were readjusted to 404 megahertz.

The total nominal power variation is 2 - 3 decibels over temperature and variation.

A reduction in weight for the total minisonde may be realized by reducing the size of the battery. Battery size may be reduced due to less power consumption. The power amplifier in the transmitter could be controlled by a logarithmic device which operates as a function of the altitude transducer. As the balloon ascends, the power out will increase at a logarithmic rate. This will provide a lower power out at close distance and increase the power out as the distance between transmitter and receiver increases.

If a larger quantity of units to be manufactured should be required, an investigation into the feasibility of thick-film hybriding the transmitters should be made. he main benefits would be an increase in the production rate and a cost reduction for manufacture.

After testing these units, it was found that the transmitter is very clean; i. e., the output is low in harmonic content and very low in distortion. This is helpful in obtaining good data reduction in the processor. The transmitter frequency is very insensitive to external loading on the antenna. This is rather unusual because most of the present sondes are very susceptible to motion of the hand or the ground in proximity to the telemetry antenna. With this transmitter, it is possible to touch the antenna, and frequency is sufficiently stable so that the receiver will still maintain the frequency lock. Apparently, this is due to the decoupling action provided by the second buffer stage in the transmitter.

E. BATTERY

The battery for the minisonde should weight less than 30 grams and be capable of powering the minisonde for 30 minutes. Based on a 1,000-foot-per-minute rise rate, this will give a 30,000-foot vertical profile measurement. The battery weight and lifetime requirements are interrelated. To enable the minisonde to operate longer, a larger and heavier battery with greater capacity could be used, but that would mean that the balloon would rise at a slower rate and it would therefore take a longer time to reach 30,000 feet. Thus, the only real improvement is to have a battery with a better energy-to-weight ratio.

The minisonde requires a current of approximately 135 milliamperes when operating at 13.5 volts. Most of this current is consumed by the transmitter, which draws 120 milliamperes. The transmitter load appears to be like a resistive load of 100 ohms. The transmitter draws 120 milliamperes at 13.6 volts and about 85 milliamperes at 10 volts. The meteorological electronics draw a constant 15 milliamperes additional current.

Four types of batteries were considered for the minisonde - a conventional water-activated battery and three types or sizes of lithium batteries. Each of these will now be discussed in more detail.

1. Eagle-Picher Water-Activated Battery

To obtain information on the conventional water-activated battery, we spoke to Mr. V. Devore at the Eagle-Picher plant in Socorro, New Mexico. This plant manufactures the magnesium-copper chloride battery currently used by the US weather bureau and other sonde users. The battery was specified at that time as a 12-volt, 80-milliampere battery with a 15-minute operating life.

Eagle-Picher makes a battery that is 1 inch wide, 2 inches high, and 1.5 inches deep. It provides a current of 430 milliamperes for 30 minutes. Eagle-Picher can make a smaller and lighter 12-volt battery by connecting eight or nine of their D-size cells in series. Such a battery would be 1 inch by 1.25 inches by 1.5 inches (1.88 cubic inches) in size. The battery weight could possibly be cut to about 60 to 75 grams. This weight is for a fully activated battery. In production at rates of about 2,000 to 10,000 batteries per year, the cost would be from $1.25 to $1.50 each. Based on the most recent tests, the battery has a shelf life of at least 7 years if maintained in a sealed, dry environment. Eagle-Picher predicts a 10-year shelf life. If the battery is stored under ambient conditions, it has a shelf life of about 10 to 100 days, depending on humidity.

This battery was rejected on the basis of its weight since it weighs more than twice the required weight. In fact, it weights almost as much as the total minisonde must weigh.

2. PCI (PCI-400-5HR) Lithium Battery

Another potential battery could be fabricated from a lithium cell manufactured by PCI Incorporated. Their model PCI-400-5HR is a small cell using the lithium sulphur dioxide electrochemistry. This cell has an open circuit voltage (OCV) of 2.95 volts and 2.2 volts when loaded with 20 ohms of resistance. It gives an operating life of better than 30 minutes over the full temperature range. Each cell is 0.5 inch diameter by 0.75 inch long. A battery would require at least four of these cells, each having a weight of 7 grams. This would give a total battery weight of 52 grams, which is significantly higher than desired. These batteries have been tested extensively by Mr. S. J. Grillo of NADC. He provided the curves shown in Figures 20 and 21.

The curve in Figure 20 illustrates the voltage versus time characteristic for the PCI-400-5HR cell when operated at room ambient temperature with a 20-ohm resistive load. The temperature characteristic of the cell is illustrated by Figure 21. It operates well over the range temperatures down to -50°C.

There is a potential safety problem when handling and storing batteries using the lithium/sulphur dioxide electrochemistry. If these cells are accidently short circuited, it is possible for them to build enough internal heating to rupture the case vents. Also, since lithium is a flammable metal when exposed to water, special handling precautions must be observed. The batteries must be shipped in a metal container and packed in water-tight, non-inflammable packing.

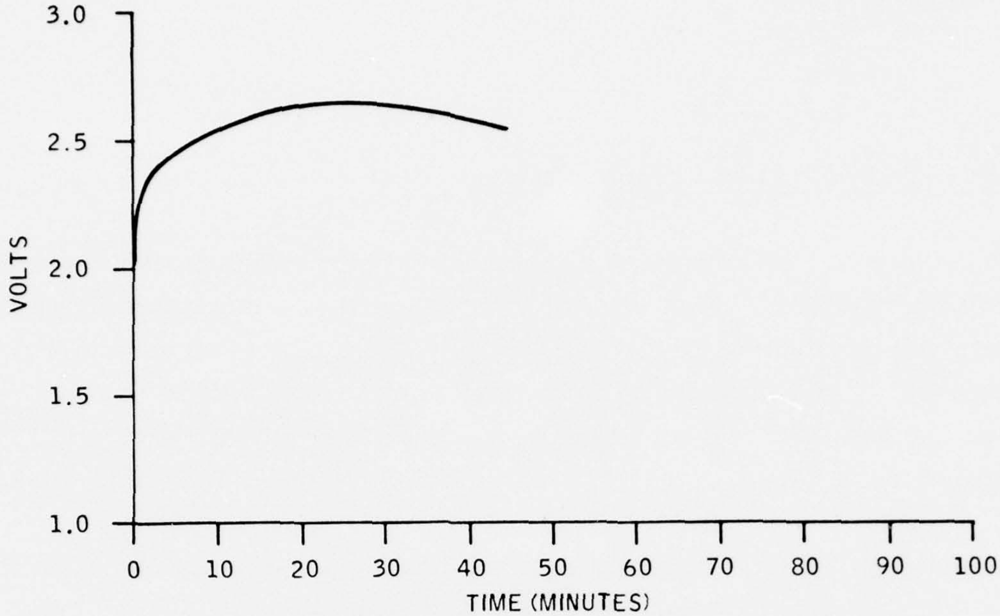


Figure 20. PCI-400-5HR Lithium Cell Voltage Versus Time Performance ($\overline{X}$ for 15 Samples)

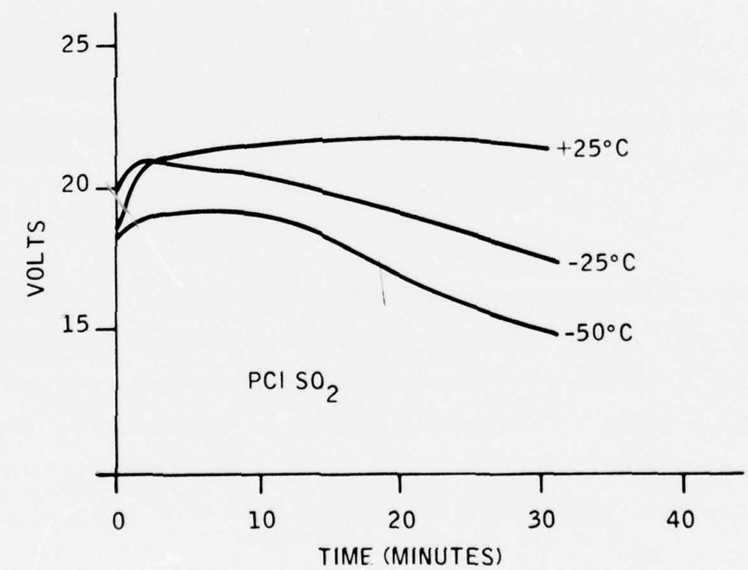


Figure 21. PCI-400-5HR Lithium Cell Temperature Performance

3. *Honeywell G3004 Lithium Battery*

A small light-weight lithium cell (shown in Figure 22) was developed by the Honeywell Power Sources Center (PSC) for use by the US Postal Service. This cell, designated the G3004, uses the lithium/vanadium pentoxide electrochemistry and is 1.25 x 2.8 x 0.06 inches in size. The battery has a polyethylene case and weighs only 4 grams per cell. The capacity of the cell is 150 milliampere-hours at a continuous discharge current of 15 milliamperes.

For testing, 40 G3004 lithium cells were constructed. These cells were made up into five-cell batteries to provide the nominal 12 volts required by the minisonde. As shown by the two engineering reports (Appendices B and C), the cells were life tested with a 22.5-ohm resistance at room temperature. The cells gave an average life of 26 minutes. This would appear to be very promising for our application. The battery consisting of five G3004 cells weighed 17 grams without an outer case. This is well within the weight restriction.

After further testing, it was determined that, to get maximum current density from the cell, it is necessary to constrain the cell or to place a weight on it. This would require that a plastic clip or some type of binding be placed around the total battery package to keep all of the electrode elements in intimate contact. This binding would add a few grams to the total battery weight, but it would still fall within the weight target.

The G3004 cells are packaged in a sealed polyethylene bag which is not as tight or impervious to chemical evaporation as the conventional crimp-sealed container. Because of this, there was some concern as to whether a 10-year shelf life could be obtained without special packaging. At this point in the investigation, a new cell, the Honeywell G3060 lithium cell, became available

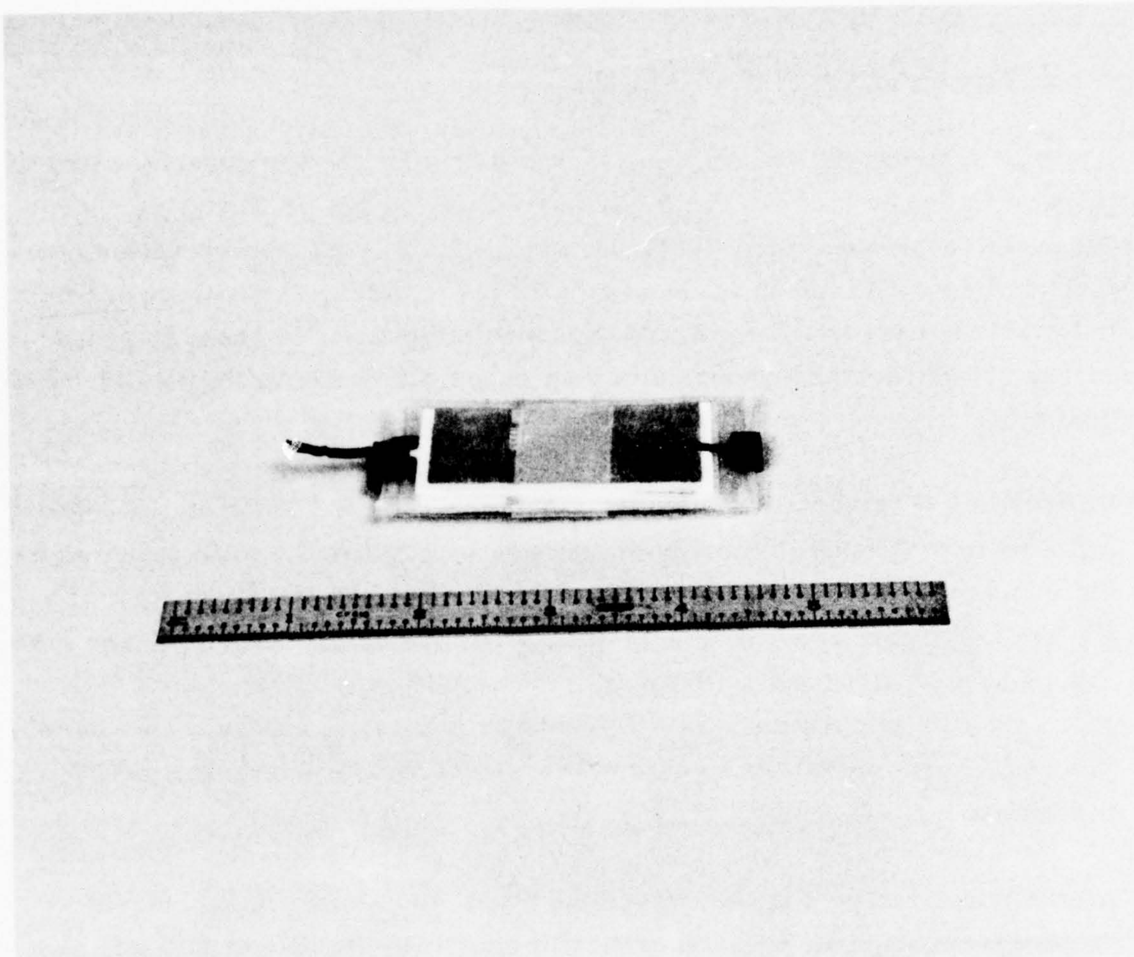


Figure 22. Honeywell G3004 Lithium Cell

from PSC. Although this cell is significantly heavier, weighing 6.3 grams per cell, it has an increased current delivery capability which is better able to power the minisonde over its total flight time. Further studies of the G3004 cell were set aside at this time in order to study the G3060 cell, which was finally used in the minisonde launches.

4. Honeywell G3060 Lithium Battery

The Honeywell G3060 cell is packaged in a disc-shaped package 1.1 inches in diameter and 0.1 inch thick for use as an electronic watch power source. The G3060 cell is of the lithium/vanadium pentoxide electrochemistry. The cell weighs 6.3 grams and has a capacity of 150 milliampere hours.

The discharge curve of a typical G3060 cell at room temperature is shown in Figure 23. This would indicate that the cell will provide adequate power for the minisonde over a 40-minute flight time. This, coupled with the total battery weight (four G3060 cells plus outer case) of 28.7 grams, makes this cell appear very attractive for many sonde operations.

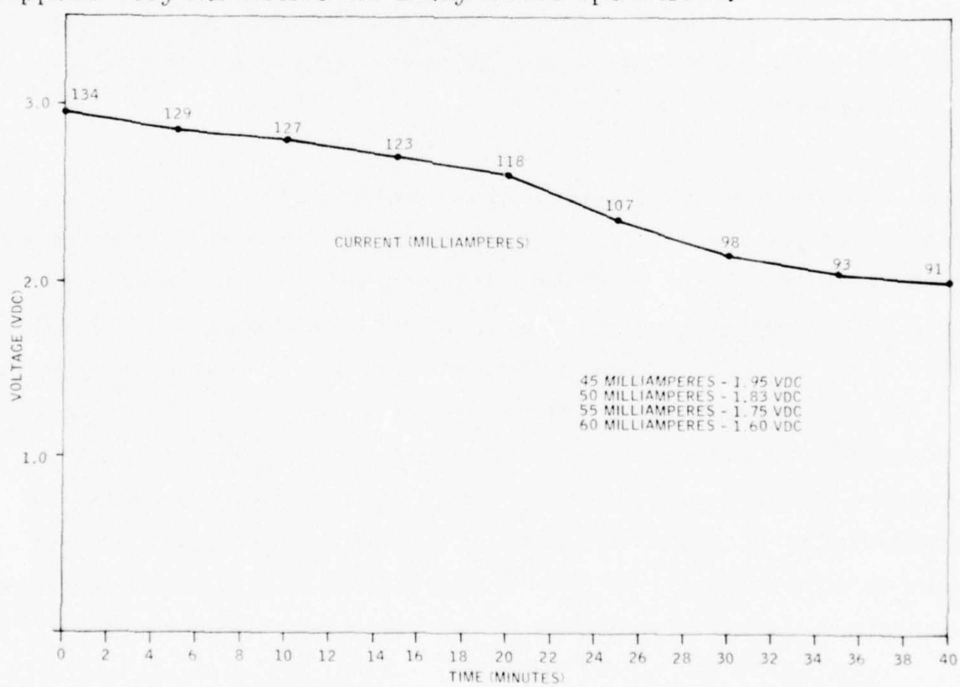
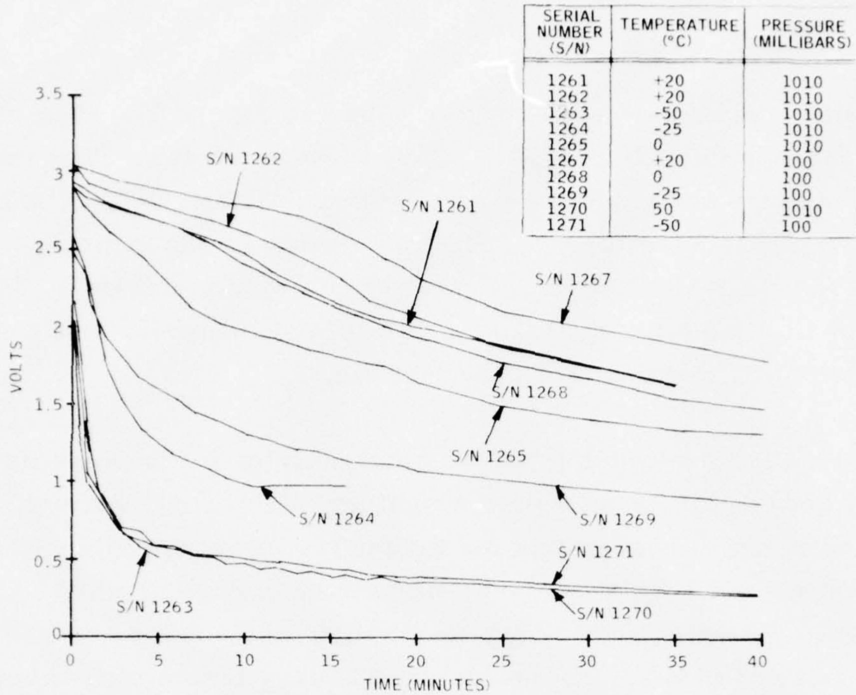


Figure 23. Honeywell Four-Cell G3060 Lithium Battery (Serial Number 1272) Voltage Versus Time Performance

One significant advantage of the G3060 cell is its safety. Because of the small amount of lithium used, the cell can be safely shorted without risk of case rupture. The tightly crimped stainless steel package used in its construction also gives the cell a potential high operating current density so that a heavier load can be drawn from the cell. Also, the tight seal produces a long-life cell, potentially 5 years or greater.

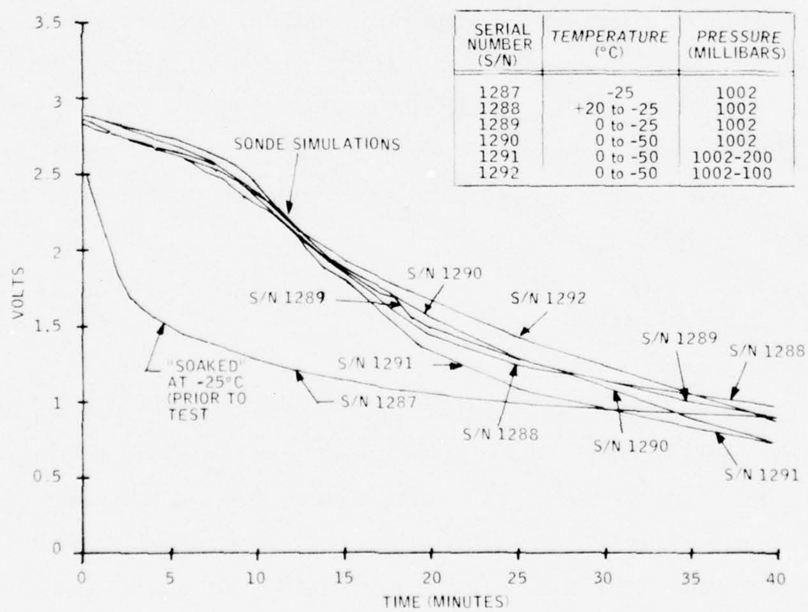
One problem with the lithium/vanadium pentoxide electrochemistry is its relatively poor low temperature operation. Temperature characteristic curves on the G3060 cell were measured by Mr. S. J. Grillo of NADC and provided to us for our use. The temperature characteristics of the G3060 cell are shown in Figures 24 and 25. In Figure 24, a series of uninsulated G3060 cells were placed in an environmental chamber operating at two pressures, 1.010 or 100 millibars, and operating over a temperature range from 20 to -50°C. The cell, in each case, was soaked at the chamber temperature prior to testing. As can be seen, the cells operate slightly better at lower pressure. However, below 0°C, their output and life are seriously decreased.

An uninsulated battery is not typical of the actual application. In the actual application, the battery will not be soaked at the very low temperatures, but will be starting initially at the launch temperature. In addition to that, the battery is placed within an insulating foam case (the minisonde case) and will actually be subject to some self-heating which will keep the temperature higher. To test the battery performance under more typical operating conditions, a package was constructed using two layers of 100-mil styrene foam, and the entire package was soaked at either +20 or 0°C, simulating initial launch conditions. The ambient temperature of the test chamber was then decreased to either -25 or -50°C over a period of 40 minutes to simulate the temperature profile of a typical balloon sounding. The results of



SERIAL NUMBER (S/N)	TEMPERATURE (°C)	PRESSURE (MILLIBARS)
1261	+20	1010
1262	+20	1010
1263	-50	1010
1264	-25	1010
1265	0	1010
1267	+20	100
1268	0	100
1269	-25	100
1270	50	1010
1271	-50	100

Figure 24. Honeywell 1-Year Watch Battery Test Results, 20-Ohm Resistive Load, 8-9 February 1977



SERIAL NUMBER (S/N)	TEMPERATURE (°C)	PRESSURE (MILLIBARS)
1287	-25	1002
1288	+20 to -25	1002
1289	0 to -25	1002
1290	0 to -50	1002
1291	0 to -50	1002-200
1292	0 to -50	1002-100

Figure 25. Honeywell 1-Year Watch Battery Test Results, 20-Ohm Resistive Load, 28 February 1977

battery voltage versus time testing are shown in Figure 25. Cell serial number 1287 was initially cooled to -25°C prior to the test. The rest of the cells were started at an initial temperature of 20 or 0°C. The lower initial operating temperature significantly decreases the output from the cell. Based on a 2-volt end of life, these tests would indicate a 13-minute operational lifetime from the battery. This is significantly less than the desired goal of 30 minutes of operational life.

The G3060 cell still appears to be the most promising power supply for the minisonde because of its very light weight and high energy density. We do need to find a way to compensate for the poorer low temperature characteristics of the cell. This can be accomplished in several ways. One is to use an 8-volt operating level in the minisonde, which allows us to have 1.6 volts per cell end of life. To maintain the battery temperature above 0°C, we can add more foam insulation around the battery to reduce its heat loss. Secondly, we can add a small heater and, if necessary, an additional cell to the four-cell battery stack to provide self-heating to maintain the temperature of the cell above 0°C. A small temperature sensor and thermostat would be incorporated with each battery to operate when the cell temperature drops below 0°C. In this way, we will be able to utilize the full capacity of the G3060 cell. These modifications will be incorporated in future minisonde developmental models.

5. Battery Selection Status

Of the four types of batteries considered, it appears that the water-activated battery and the PCI battery (lithium/sulphur dioxide electrochemistry) are heavier than desired, although they would have enough capacity to operate the minisonde. It appears that the lithium/vanadium pentoxide electrochemistry is more appropriate from the standpoint of safety handling and storage. However, the poorer low temperature properties must be compensated for. The

Honeywell G3004 battery has the best weight factor, but its energy output is marginal. The Honeywell G3060 battery appears to be the best tradeoff for energy versus weight in an available battery. G3060 cells will be used for batteries in the next stage of minisonde development.

F. BALLOON

The desired requirements for the balloon are that a 30-gram latex balloon be inflated to a maximum diameter of 30 inches. The balloon and minisonde should rise at a 1,000-foot-per-minute rate and attain an altitude of greater than 20,000 feet before the balloon bursts.

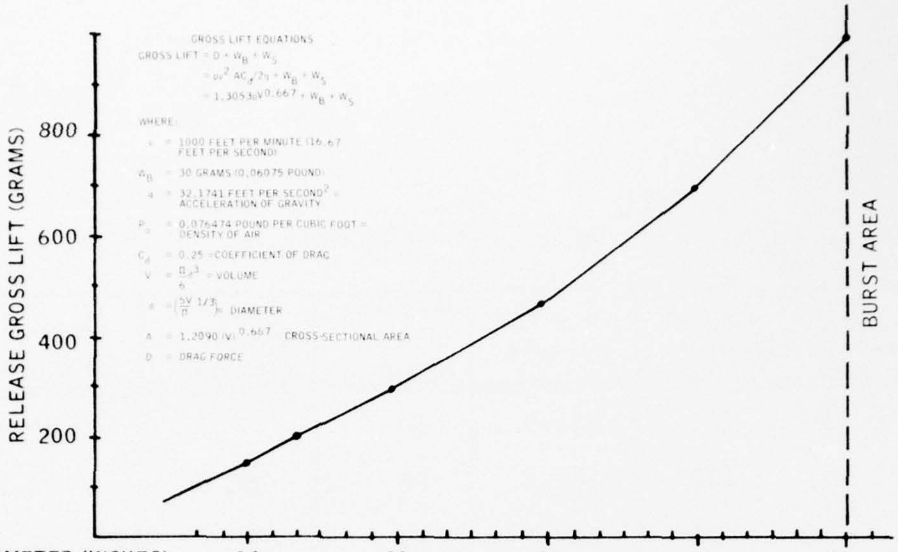
For a balloon, both the conventional latex piball balloon and a 1/2-mil mylar plastic film balloon were considered. The latex balloon has the advantage of being low in cost and readily available since it has been used for a number of years. It is a well proven balloon. The problem with latex ballons is that they tend to be fragile and sometimes require preconditioning. A film balloon, on the other hand, made of 1/2-mil mylar, would be more durable and would not require preconditioning. The potential of designing a film balloon for the minisonde was discussed with Raven Industires of Sioux Falls, South Dakota. They indicated that a film balloon would be heavier than a latex balloon for the same diameter and same maximum altitude. In addition, a film balloon would cost \$5 to \$10 compared to the less than \$1 price for a latex balloon. It would appear that a latex balloon is the most practical solution for the minisonde.

For a latex balloon, the rate of rise of the balloon/minisonde package is determined by the weight of the minisonde and balloon and the initial diameter of the balloon. In other words, the larger the balloon or the smaller the package, the greater will be the lift. The maximum altitude is determined by the maximum inflated diameter of the balloon; in the case of a 30-gram balloon, it will typically reach 48 inches of diameter before it bursts. Thus, it can be seen that there is a tradeoff between the rate of rise, minisonde weight, and maximum altitude.

To calculate the exact performance of the balloon/minisonde package, data were provided by Mr. S. J. Grillo of NADC. A plot of the gross lift versus balloon diameter and volume is shown in Figure 26. Gross lift equations are also provided in the figure.

Based on a 30-gram latex balloon and a 1,000-foot-per-minute rise rate, the maximum altitude is shown by Figure 27. The maximum altitude or burst altitude is tabulated for several typical balloon diameters in Table 6. To determine burst altitude for a given minisonde weight, refer to Figure 27. Starting on the minisonde weight axis for an 86-gram minisonde weight, draw a vertical line to intersect the curves. Going from the intersection with the diameter line and moving to the right hand scale indicates that a 30-inch balloon diameter is required at launch. Going to the intersection with the altitude line and reading to the left hand scale indicates a maximum altitude of 29,000 feet. Referring to Figure 26 shows that a 30-inch-diameter balloon has a gross lift of 300 grams. Subtracting the weight of the balloon and the weight of the minisonde, there is a free lift of 183.8 grams available. This now indicates how much helium must be put into the balloon prior to the launch.

The amount of helium to be put into the balloon before launch can be determined using the fixture illustrated in Figure 28. A 30-gram latex balloon is rolled over a nozzle weighing exactly 270 grams, and then enough helium is inserted into the balloon to just lift this nozzle off from the floor. At that time, the balloon will have 184 grams of free lift when the minisonde is attached.



DIAMETER (INCHES)	24	30	36	42	48
DIAMETER (FEET)	2.0	2.5	3.0	3.5	4.0
VOLUME (CUBIC FEET)	4.19	8.18	14.14	22.45	33.51
VOLUME$^{0.667}$	2.59	4.06	5.92	7.96	10.39

Figure 26. Balloon Data and Gross Lift Equations

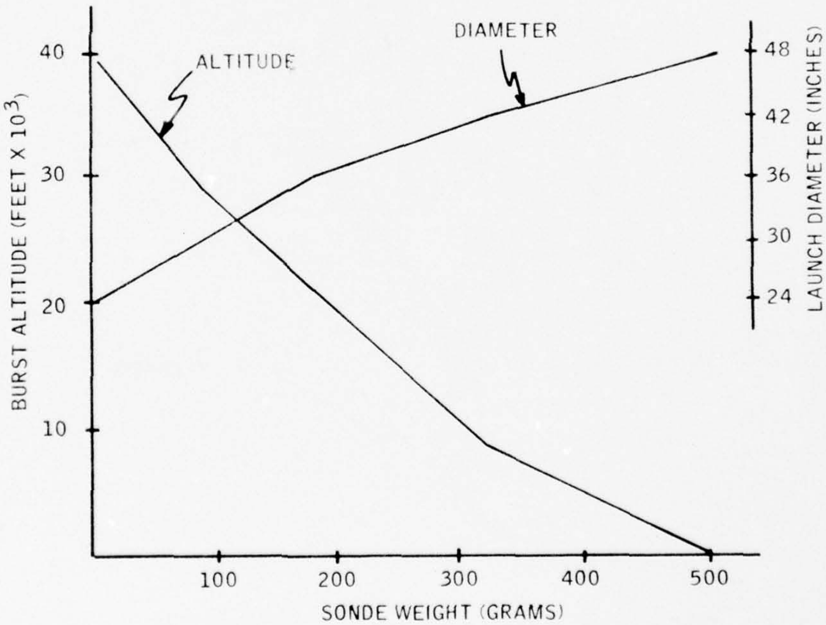


Figure 27. Sonde Performance Versus Weight for a 30-Gram Balloon with a Rise Rate of 1000 Feet Per Minute

Table 6. Balloon Data

Diameter (Inches)	Gross Lift (Grams)	Free Lift (Grams)	Balloon Weight (Grams)	Sonde Weight (Grams)	Burst Height (feet x 10^3)
24	150	117.7	30	2.3	39.8
30	300	183.8	30	86.2	28.8
36	475	267.9	30	177.1	21.3
42	700	360.2	30	309.8	8.8
48	1000	470.5	30	499.5	0

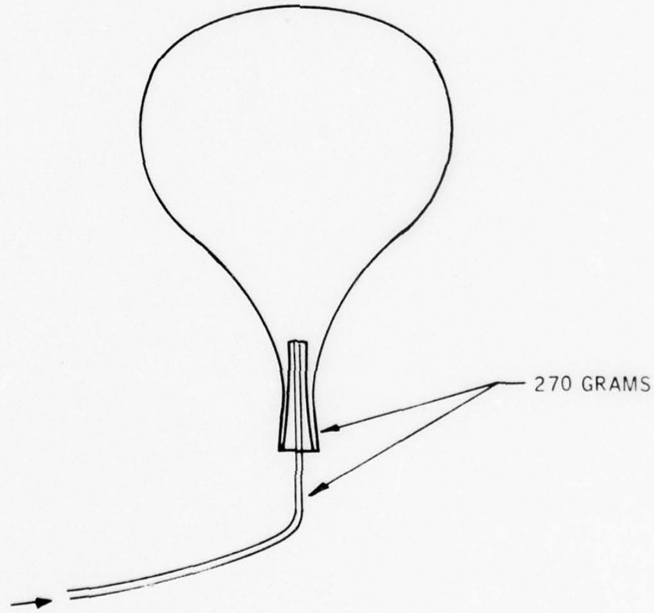


Figure 28. Balloon Filling Procedure

III. MINISONDE CONSTRUCTION AND PACKAGING

The package for a minisonde is very important because it has to meet the conflicting requirements of being strong enough to withstand handling and field launch and at the same time being light enough so that it can be launched by a 30-gram balloon. The requirements for the package are that it must provide adequate air flow for the sensors, that it must provide shielding from solar radiation and rain, and that it must be strong enough so that it can be easily handled. The maximum desired weight of the balloon and minisonde together is 100 grams.

A total minisonde was constructed as shown in the photograph of Figure 29. The minisonde and a 30-gram latex balloon as shown are ready for launch.

An exploded view of the minisonde is shown in Figure 30 to illustrate all of the subassemblies. We will now discuss the subassemblies of the minisonde shown in Figure 30, and then each of the subsystems will be discussed (see Figures 31 - 42). Starting at the top of the minisonde of Figure 30 are the sensors. The temperature sensing thermistor is placed directly on top of an air duct at the top of the minisonde. In this way, it will measure true free air temperature. The air duct for the thermistor goes beneath the humidity sensing carbon hygristor and comes out of two ports on the sides marked air duct exit. To the left and below the thermistor is the carbon hygristor. The hygristor is mounted in two spring wire clips which do not restrict the air flow past the sensor. A radiation shield cover is placed over the top of the sensor to form an air duct. The radiation shield is white on the outside to reflect solar radiation and black on the inside to inhibit any transmission of solar energy through the shield. The area around the hygristor is also blackened to avoid reflection of solar energy down the air duct channel. Note that the air flow from the thermistor channel goes beneath the hygristor to avoid

Figure 29. Minisonde and 30-Gram Balloon

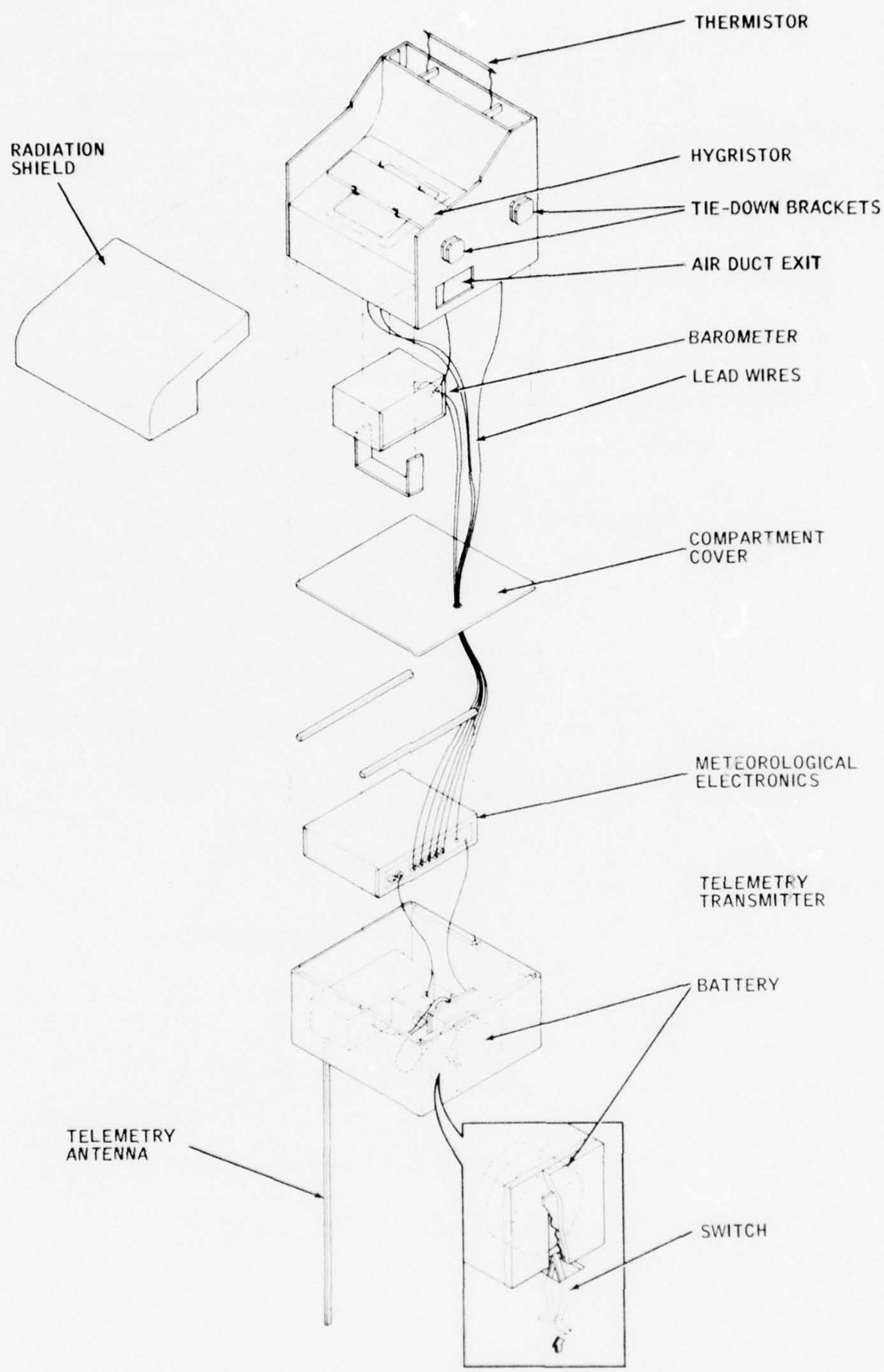


Figure 30. Exploded View of Minisonde Showing Subassemblies

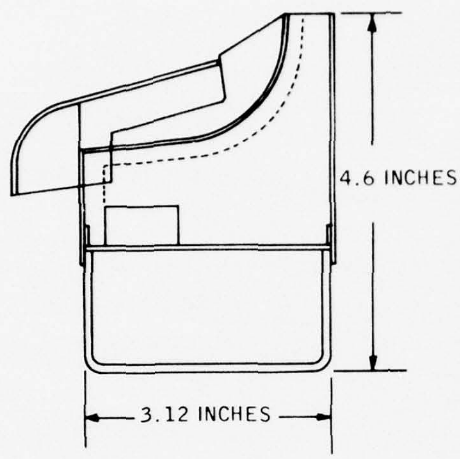


Figure 31. Minisonde Case

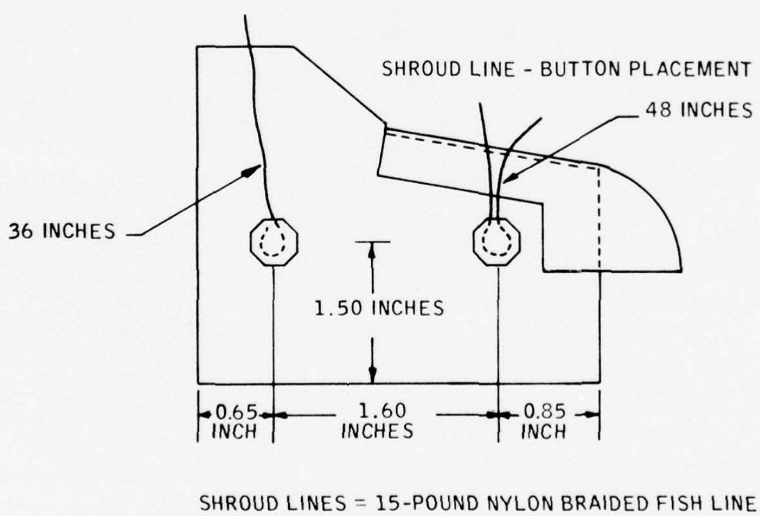


Figure 32. Minisonde Case Construction

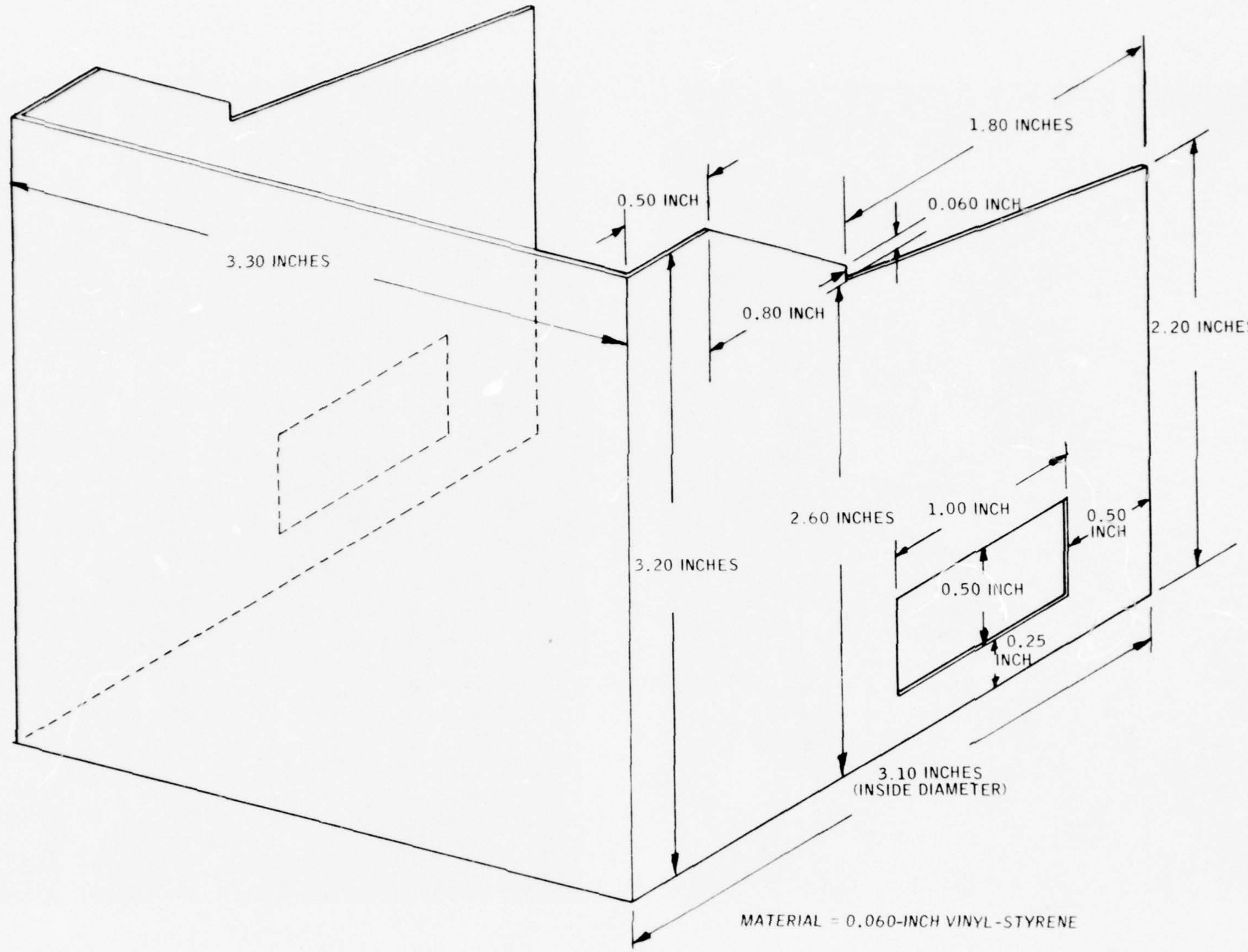


Figure 33. Minisonde Construction

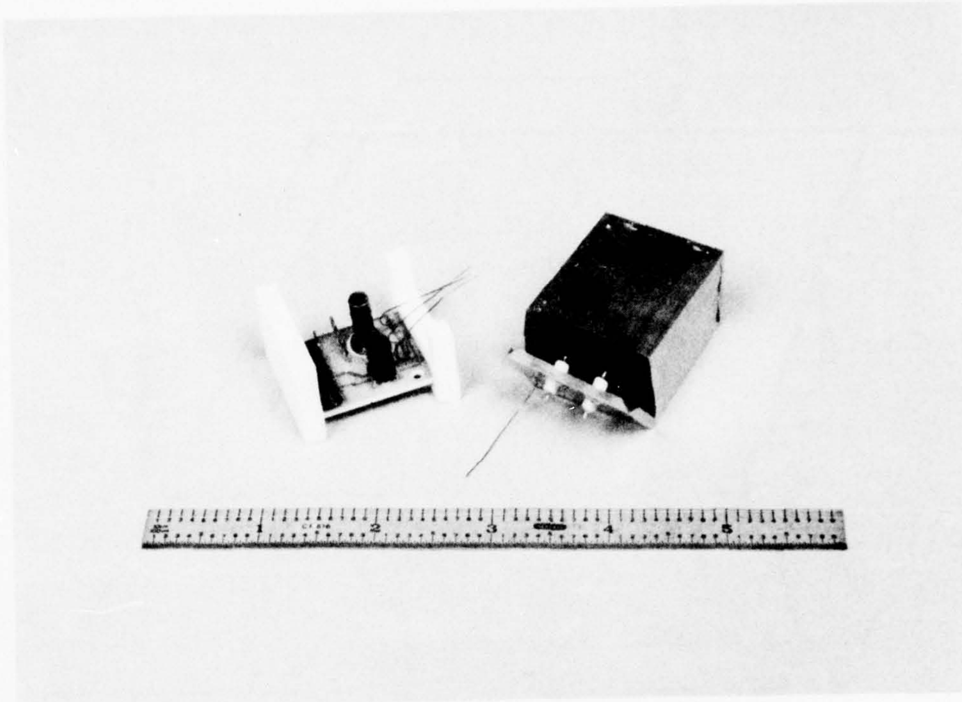


Figure 34. Barometer Piece Parts

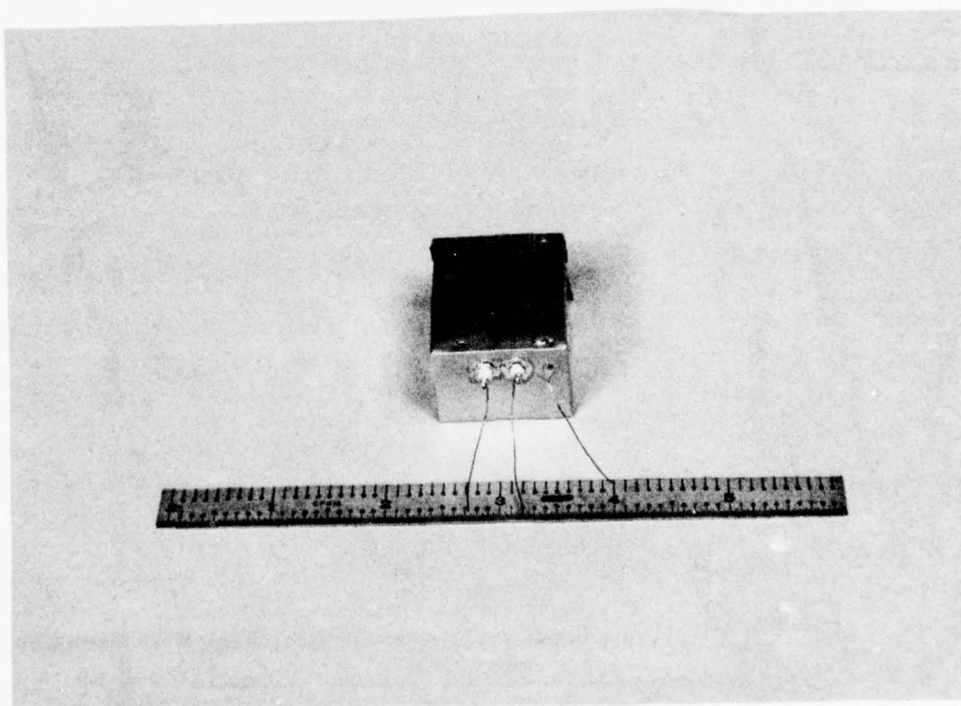
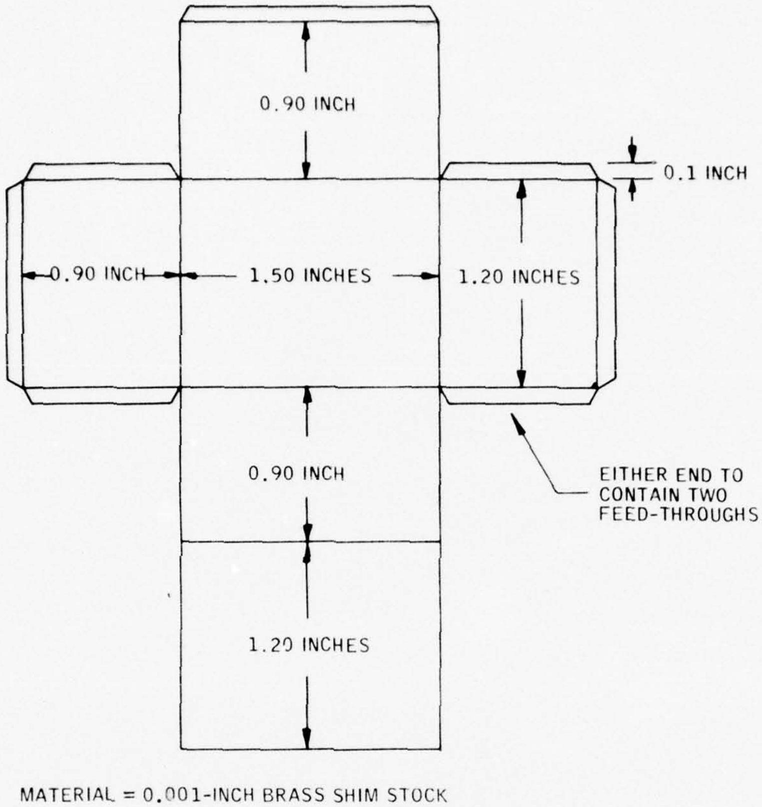


Figure 35. Assembled Barometer



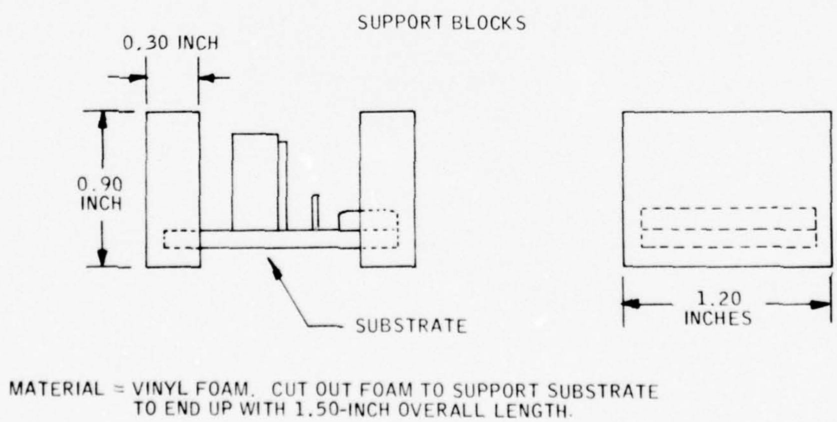


Figure 36. Barometer Housing

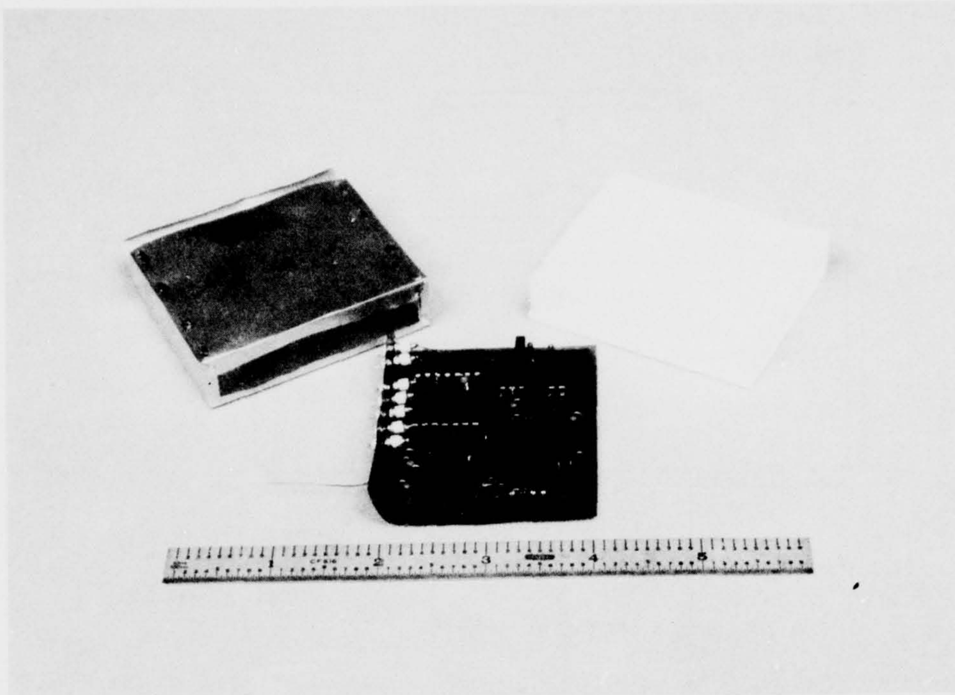


Figure 37. Meteorological Electronics Components

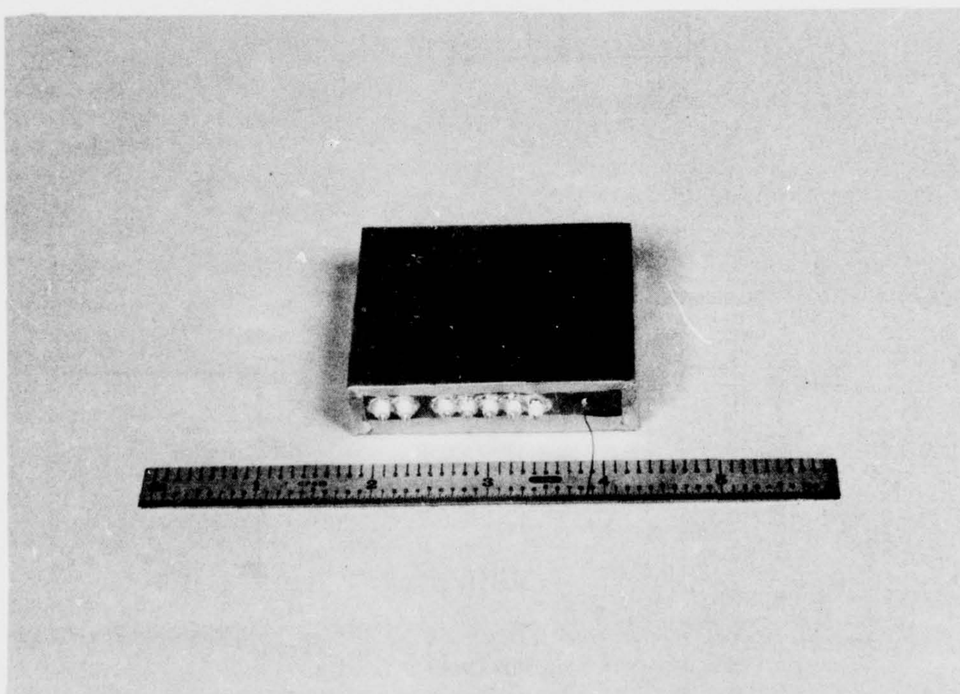


Figure 38. Meteorological Electronics Assembly

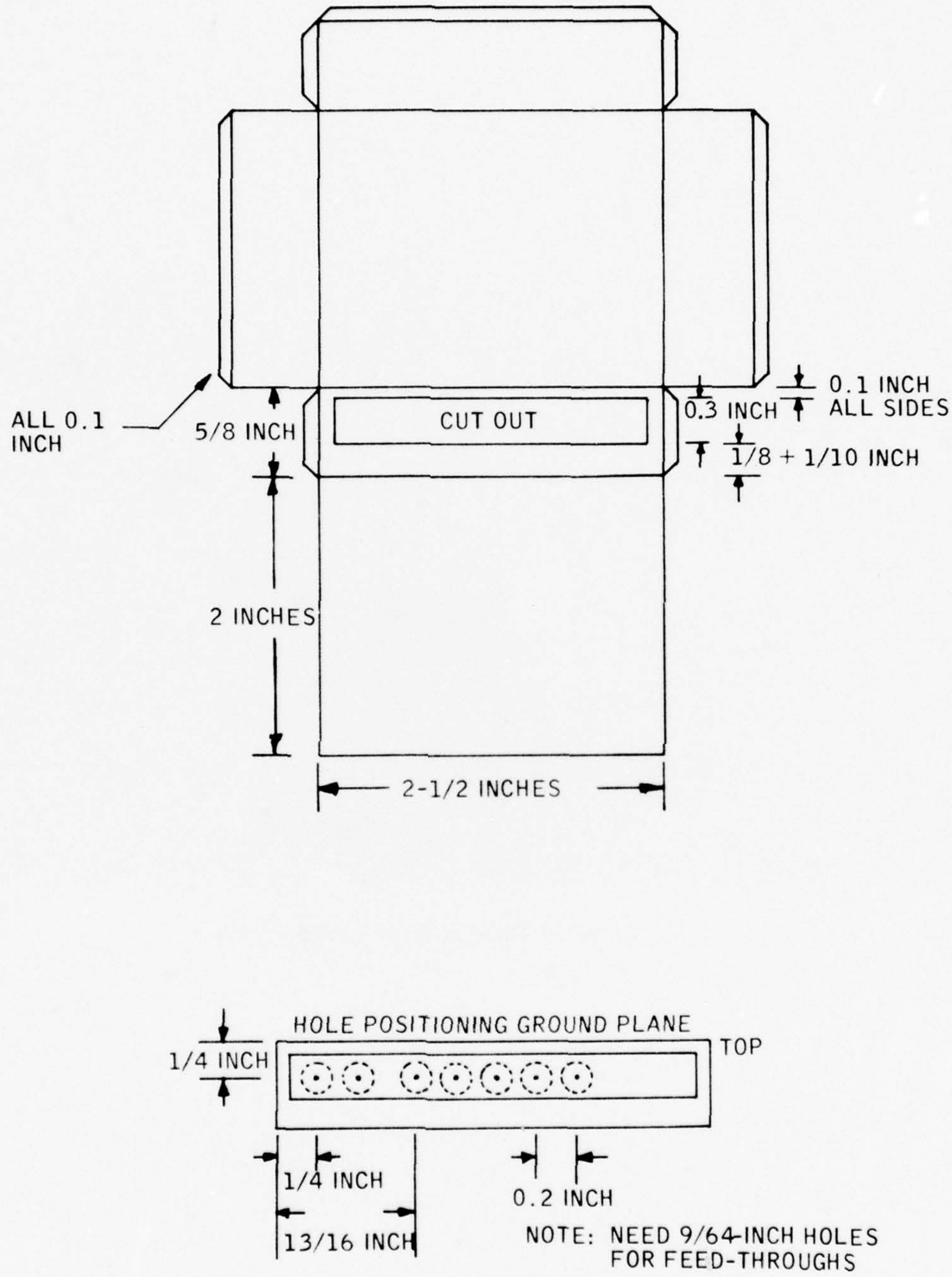


Figure 39. Meteorological Electronics Shielding

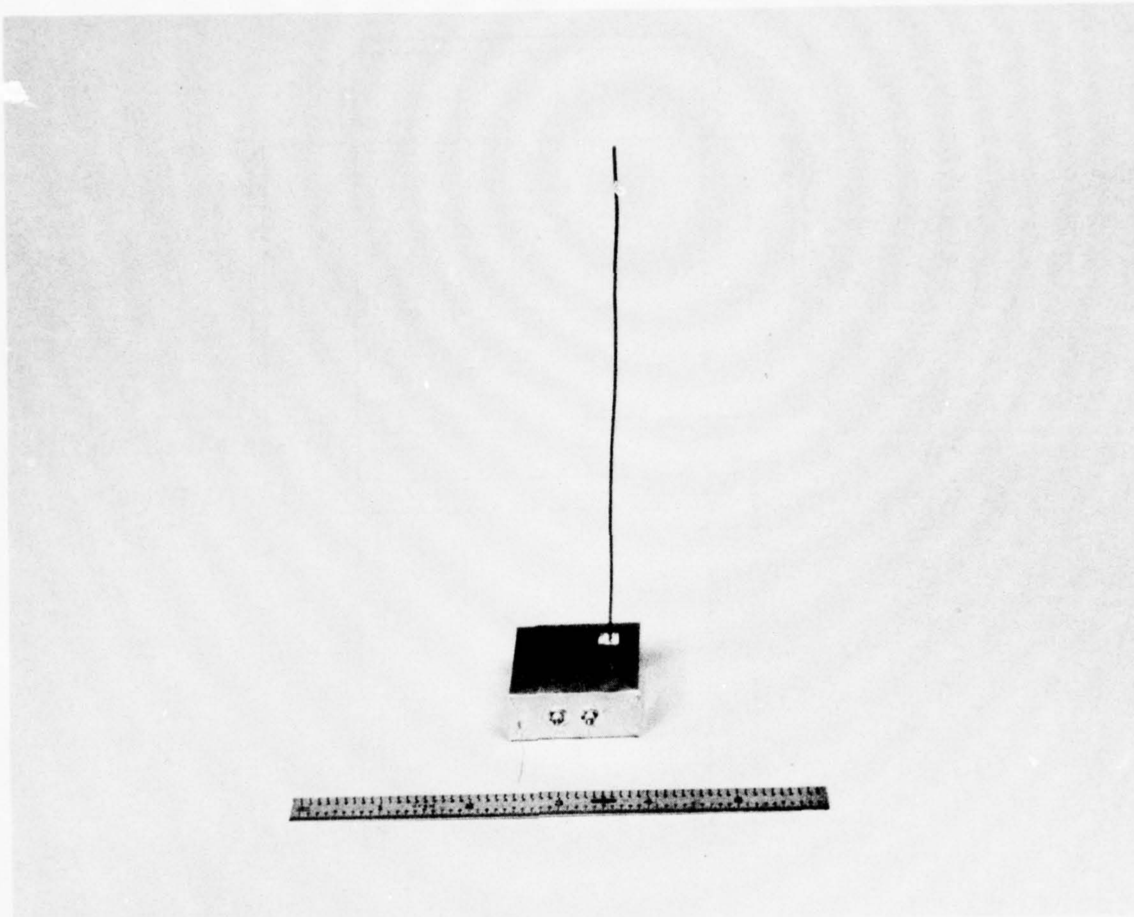


Figure 40. Telemetry Transmitter

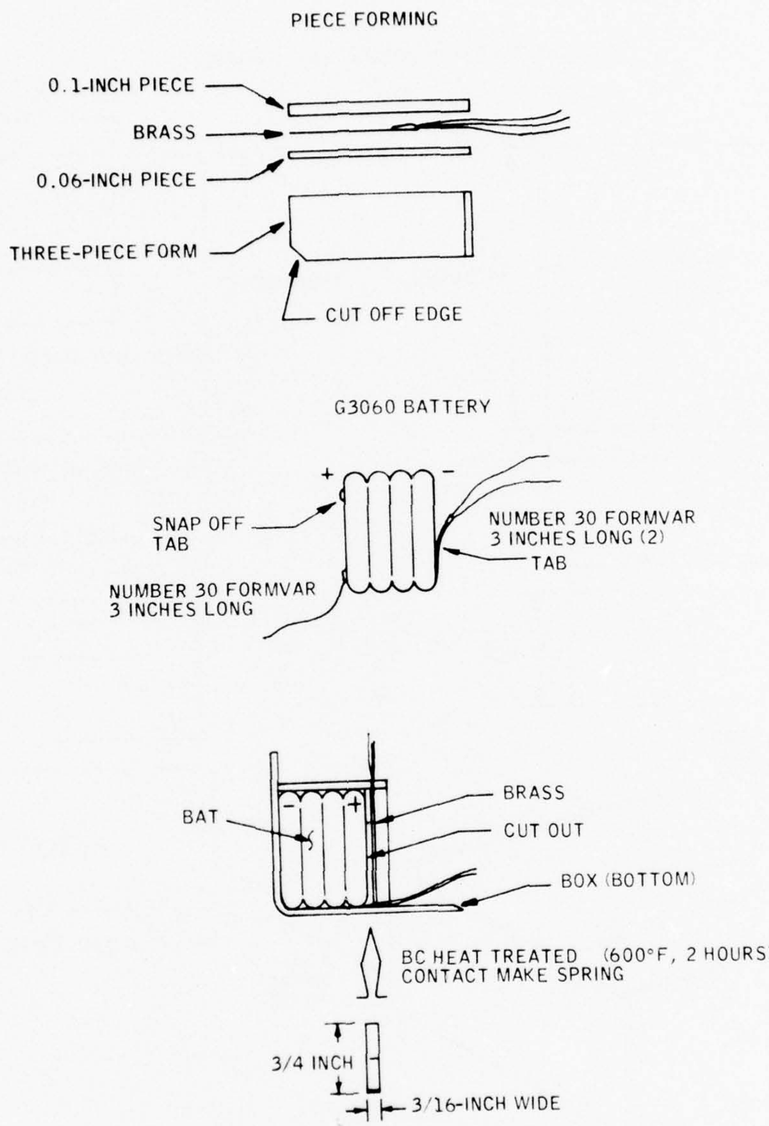


Figure 41. Battery and Switch Construction

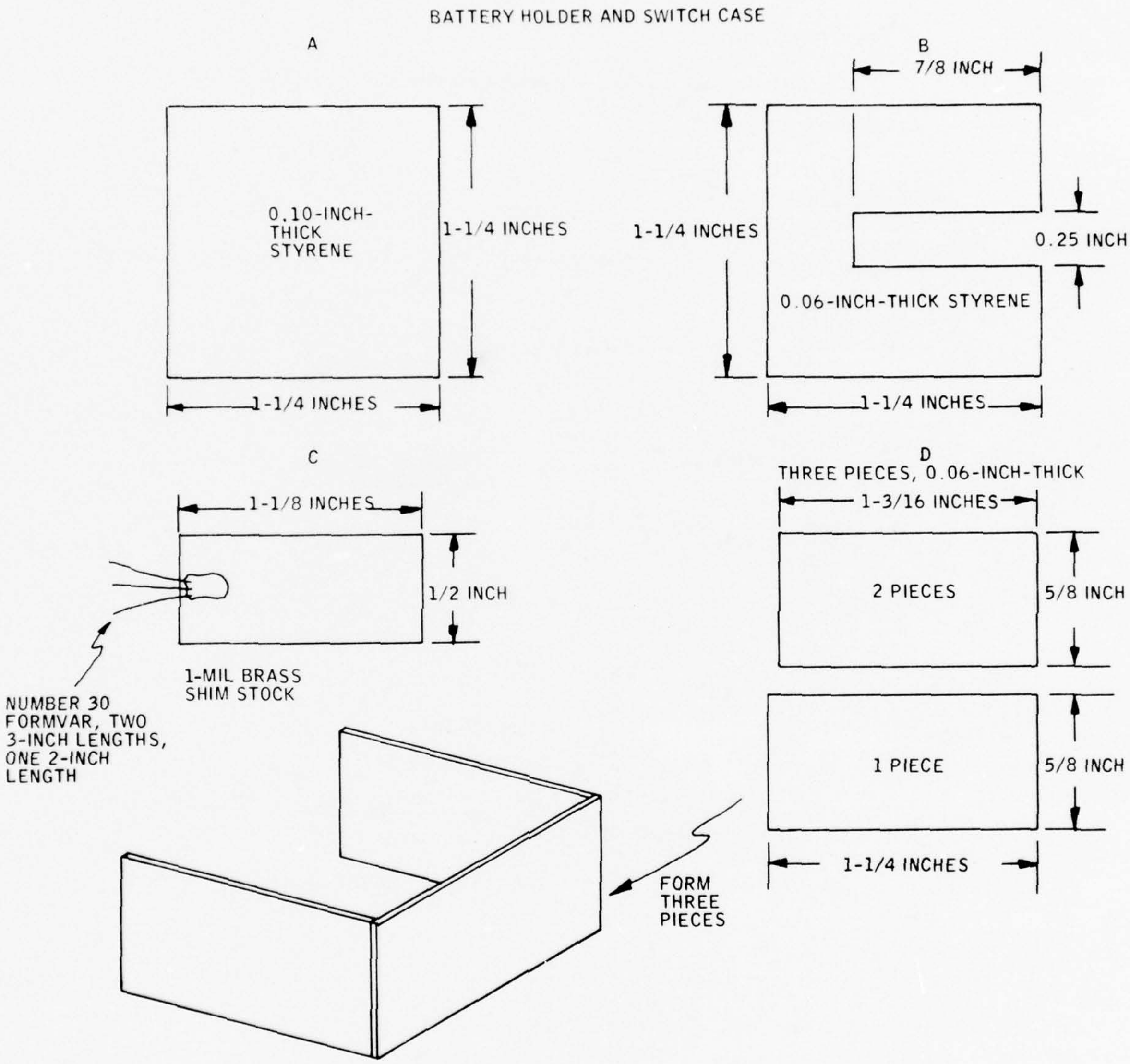


Figure 41. Battery and Switch Construction (Concluded)

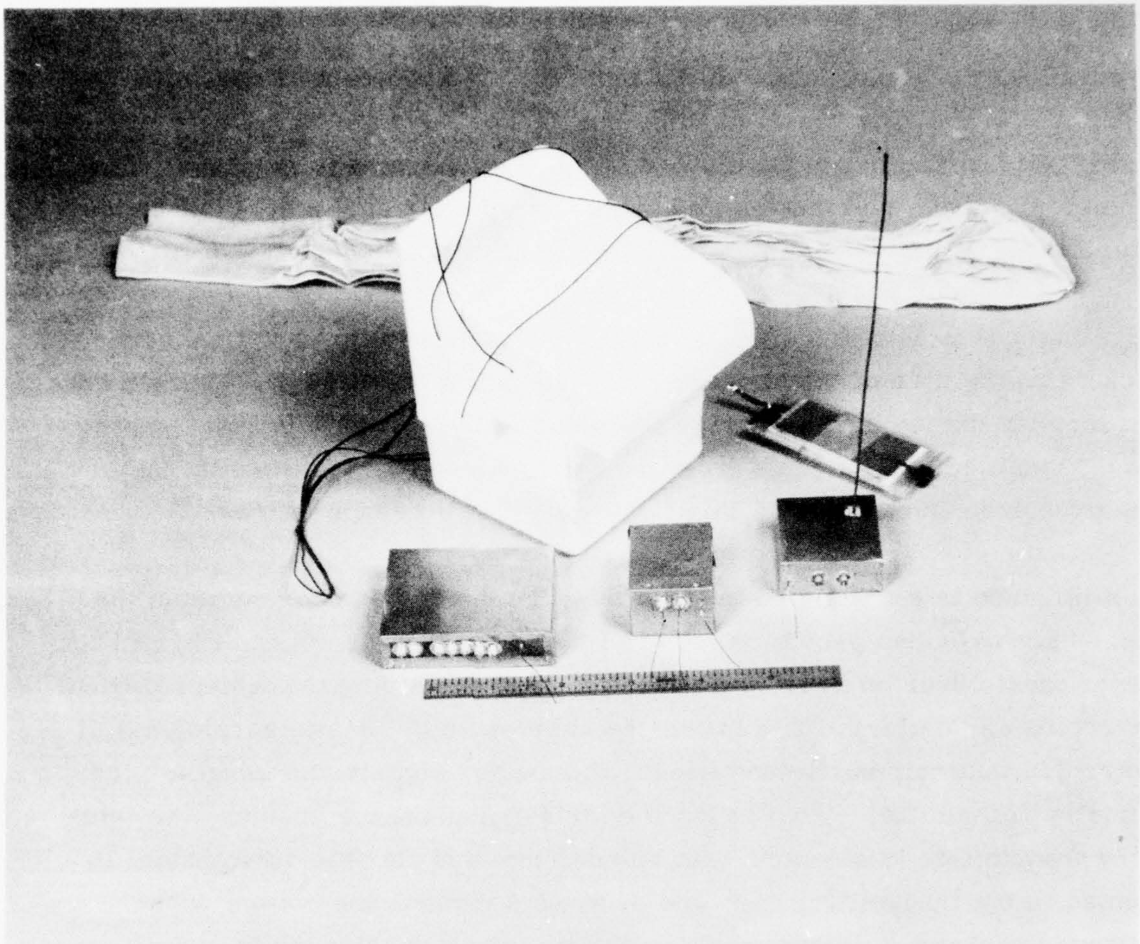


Figure 42. Minisonde Component Parts

any possibility of temperature effect from the electronics package below the hygristor. In the chamber formed by the temperature air duct, the pressure sensing silicon diaphragm barometer in its shielded case is mounted. The barometer is located below the hygristor near the air duct exit. The barometer is kept at ambient temperature by the air flow through the duct.

The minisonde is launched by fish line cord attached to the four tie-down brackets on the side of the package. The radiation shield is held on by a cord going across the top of the package from one of the tie-down brackets to the other. The electrical signals from the sensors are carried down to the meteorological electronics by thin light-weight solid copper wires.

The minisonde is constructed in two parts; the upper chamber contains the sensors and provides provision for air flow, and the lower chamber from the compartment cover on down is a watertight box containing the meteorological electronics and battery. The lower chamber contains the meteorological electronics that commutate and encode the sensor signals and modulate the telemetry transmitter. Just below the meteorological electronics, the telemetry transmitter is mounted. An antenna made of flexible spring steel is mounted in the transmitter case and protrudes through the bottom of the minisonde package. The antenna is, effectively, a quarter-wave ground plane antenna, with the remainder of the electronics and minisonde wiring serving as the ground plane. Power for the minisonde is provided by a battery consisting of four G3060 cells. The battery package is located in the lower right hand corner of Figure 30. To energize the minisonde battery, a spring metal clip is pushed into the bottom of the minisonde which makes contact between the battery and a metal plate. The minisonde can be turned off by withdrawing this metal clip.

All electronics packages, including the barometer, meteorological electronics, and telemetry transmitter, are shielded with a 1-mil shim brass case. The purpose of this shielding is to eliminate pickup of the 403-megahertz telemetry transmitter signal by the electronic circuits. If the circuits were not shielded, the RF signal would be picked up and rectified by the circuitry. These signals would cause an offset in the electronics and an error in the data measurement. In addition to the shielded packages, feed-through gaskets were used on each of the signal lead wires. As discussed in Section IV, there is no apparent problem with pickup from the transmitter.

The minisonde case was constructed from 0.060-inch foam styrene sheet. The foam styrene sheets were vacuumformed around wooden blocks to provide the individual pieces that were assembled to form the minisonde case as shown in Figure 31. This case is approximately 3 inches square by 4-1/2 inches high. The case was kept small to minimize the weight, yet large enough to accommodate the sensors and required air flow. Detailed drawings of the air duct assembly are shown in Figures 32 and 33.

The piece parts of the barometer are shown in Figure 34. On the left is the barometer with its electronics on a ceramic substrate. This device is supported by styrofoam blocks to keep it centered inside of the shield, which is shown on the right half of the picture. The total assembled and shielded barometer is shown in the photograph in Figure 35. Details of the pressure transducer housing and supports are shown in Figure 36.

The parts of the meteorological electronics package are shown in Figure 37. At the lower center part of the photograph are the electronics and circuit board. The upper right portion of the photograph shows the styrofoam insulation, and the upper left part of the photograph shows the 1-mil shielded case. The meteorological electronics are mounted on a special light-weight flex substrate material to minimize the total minisonde weight. The assembled meteorological electronics package is shown in the photograph of Figure 38. A detail of the shielding is shown in the drawing of Figure 39. A photograph of the assembled telemetry transmitter and antenna is shown in Figure 40.

The minisonde battery is made up of four G3060 lithium cells. The cells are connected together by spot welding tabs between the cells. A short section of shrink tubing holds the cells together to form a battery. Figure 41 shows the battery and switch construction. The battery and switch are enclosed in a styrene package as shown in detail in Figure 41. For the next minisonde models, it would probably be easier to eliminate the switch and turn on the minisonde by inserting the battery into the case.

A photograph of the minisonde and its subassemblies is shown in Figure 42. Behind the minisonde case is a 30-gram latex balloon. To the right of the case is a G3004 lithium battery. In the front of the minisonde at the left is the meteorological electronics package, in the center is the barometer, and on the right is the telemetry transmitter and antenna.

A light-weight minisonde is now practical because of the availability of the solid-state barometers and also light-weight batteries. In addition to this, the weight of all the other subassemblies have been reduced to a minimum to make the minisonde as light as practical. The total weight of the minisonde is 86.6 grams including the battery. The weight of each subassembly of the minisonde is tabulated in Table 7.

Table 7. Minisonde Subassembly Weights

Subassembly	Weight (Grams)
Telemetry Transmitter	13.9
Barometer	11.0
Hygristor	1.3
Thermistor	0.5
Battery	28.7
Meteorological Electronics	15.2
Package	16
Total	86.6

With further developmental work, it would be possible to reduce the weight of the minisonde even further. The meteorological electronics could be integrated into a single chip. Also, the telemetry transmitter could be constructed using thick-film technology. A new battery designed along the lines of the uncased lithium cell could possibly reduce the weight of this major subassembly in the minisonde.

The minisonde was attached to the balloon by a 30-foot cord. The balloon train should be as long as possible to reduce the effect of balloon heating on the air temperature moving past the minisonde. As the balloon and minisonde ascend, the air moving past the balloon will be heated slightly. The minisonde is then pulled through this heated air. It is desirable to keep the minisonde as far from the balloon as possible so that this heat can be dissipated. Considering the relative cross-sectional areas of the 1, 000-gram balloon and the 30-gram balloon, the minisonde is proportionately further removed from any effects of the balloon temperature on free air temperature.

IV. SYSTEM TESTS

A. LABORATORY TESTS

The minisondes were constructed as discussed in the previous section. When powered with an external power supply, all minisondes commutated and telemetered data to an RF receiver. No environmental tests were performed on the minisondes prior to launch. Each of the subassemblies of the minisonde was tested as described in Section II.

Each of the meteorological electronics packages was calibrated individually. The calibrations are tabulated in Table 8.

It is possible for the RF signal from the telemetry transmitter to interface with the sensors and cause erroneous measurements. To test for crosstalk from the transmitter, each minisonde was energized. The output frequency from the VCO was measured with a digital counter. The output frequency was measured first with the transmitter off, then with the transmitter on, and then with the transmitter off again. The measured frequencies are listed in Table 9. There is no apparent effect from the transmitter. The variations from on to off are about the same as in successive readings with the transmitter on. From this, we can conclude that the shielding is adequate and that there is no problem with internal RF interference.

B. DATA REDUCTION

The minisonde sensors provide a voltage signal that is converted to frequency by the VCO. This frequency is telemetered to the ground processor where it must be decoded to reduce the data back to temperature and humidity versus altitude readings. The data reduction procedure is as follows:

Table 8. Meteorological Electronics Package Calibration Data

Unit S/N 1

V_{CC} = 9.076 VDC (Input 12.000 VDC)

High Reference (HR) = 6.520 VDC (Pin 3, 13-4052) (9, 10 Low)

F_o at High Reference = 2027 hertz

Select R_{13} = 5,360 ohms

V_{CC} = 1.392 High Reference, V_i = 0.003217 volt per hertz; Select resistor = 360,000 ohms, 9.8 hertz, 102 milliseconds

Unit S/N 2

V_{CC} = 8.999 VDC (Input = 12.000 VDC)

High Reference (HR) = 6.460 VDC (pin 3, 13-4052) (9, 10 Low)

F_o at High Reference = 2004 hertz

Select R_{13} = 5,360 ohms

V_{CC} = 1.393 High Reference, V_i = 0.003224 volt per hertz; Select resistor = 390,000 ohms, 9.9 hertz, 101 milliseconds

Unit S/N 3

V_{CC} = 9.007 VDC (Input 12.000 VDC)

High Reference (HR) = 6.470 VDC (Pin 3, 13-4052) (9, 10 Low)

F_o at High Reference (HR) = 2013 hertz

Select R_{13} = 5,360 ohms

V_{CC} = 1.392 High Reference, V_i = 0.003214 volt per hertz; Select resistor = 390,000 ohms, 9.7 hertz, 103 milliseconds

Unit S/N 4

V_{CC} = 8.989 VDC (Input 12.000 VDC)

High Reference (HR) = 6.449 VDC (Pin 3, 13-4052) (9, 10 Low)

F_o at High Reference = 2020 hertz

Select R_{13} = 5,760 ohms

V_{CC} = 1.394 High Reference, V_i = 0.003193 volt per hertz; Select resistor = 360,000 ohms, 9.8 hertz, 102 milliseconds

Unit S/N 5

V_{CC} = 8.968 VDC (Input 12.000 VDC)

High Reference (HR) = 6.443 VDC (Pin 3, 13-4052) (9, 10 Low)

F_o at High Reference = 2008 hertz

Select R_{13} = 5,360 ohms

V_{CC} = 1.392 High Reference, V_i = 0.003209 volt per hertz; Select resistor = 360,000 ohms, 9.8 hertz, 102 milliseconds

Unit S/N 6

V_{CC} = 8.942 VDC (Input 12.000 VDC)

High Reference = $\approx$ 6.416 VDC (pin 3, 13-4052) (9, 10 Low)

F_o at High Reference = $\approx$1997 hertz

Select R_{13} = 5,230 ohms

V_{CC} = 1.394 High Reference, V_i = 0.003213 volt per hertz; Select resistor = 430,000 ohms, 9.6 hertz, 104 milliseconds

Table 9. Telemetry Transmitter Interference Test Data

Serial Number	Parameter	Off	On	Off
1	High Reference	188.30	188.45	188.55
	Temperature	53.25	52.95	53.45
	Pressure	156.60	156.50	156.85
	Relative Humidity	133.10	133.10	133.45
2	High Reference	185.40	185.30	185.55
	Temperature	53.40	53.25	53.30
	Pressure	154.25	154.10	154.25
	Relative Humidity	131.55	131.45	131.70
3	High Reference	188.15	188.05	188.00
	Temperature	42.65	42.60	42.50
	Pressure	156.50	156.45	156.55
	Relative Humidity	131.55	131.10	131.00
4	High Reference	188.35	188.20	188.35
	Temperature	37.70	37.60	37.55
	Pressure	156.65	156.60	156.70
	Relative Humidity	134.85	134.85	135.00
5	High Reference	186.50	186.30	186.90
	Temperature	24.35	24.60	24.35
	Pressure	155.25	155.10	155.50
	Relative Humidity	128.70	128.60	129.00

- Convert from frequency (200-2,000 hertz) to voltage (0.6-6 volts) using the voltage-to-frequency transfer function of the minisonde VCO.

- For temperature and humidity, convert from voltage to resistance using the sensor resistance network transfer function.

- For pressure, convert from voltage to pressure using the solid-state barometer transfer function.

- Convert from resistance to temperature or humidity using the sensor conversion equation or chart.

- Convert from pressure to altitude using the barometric equation.

1. Voltage-to-Frequency Conversion

The voltage-to-frequency conversion is accomplished in the minisonde by a VCO as described in Section II. The VCO has a linear transfer function and passes through the origin. Thus, the VCO output can be described by the equation $y = mx$. Only one point on the curve is required to define the value of m. The minisonde VCOs were set to have an output of 2025 hertz with an input of 6.5 volts. The frequency-to-voltage transfer function is:

$$V_{in} = 6.5/2025 = 0.00321 \text{ volt per hertz} \tag{11}$$

2. High Reference and Supply Voltage

The supply voltage V_{CC} is needed to determine the resistance ratio for each of the sensors. Supply voltage can be determined from the high reference (HR) voltage signal. The ratio of resistor R_5 to R_6 as shown in Figure 6 and repeated in Figure 43 determines the HR voltage. The ratio is chosen so that the voltage at pin OX of U3 will be higher than the voltage signal from any of the other sensors. The high reference frequency is typically 2,000 hertz. With the values used for R_5 and R_6, the supply voltage is 1.392 times larger than the HR signal:

$$V_{CC} = 1.392\ V_{HR} \tag{12}$$

3. Temperature Calculation

There are three steps in the calculation of free air temperature from the telemetered frequency - conversion from frequency to voltage, conversion from voltage to resistance, and conversion from thermistor resistance to temperature. To convert from frequency to voltage $[E_o(T)]$, the frequency for the thermistor is multiplied by 0.00321 as defined in equation 11. Referring to Figure 43, the thermistor R_T is in a divider with resistor R7. R_T can be

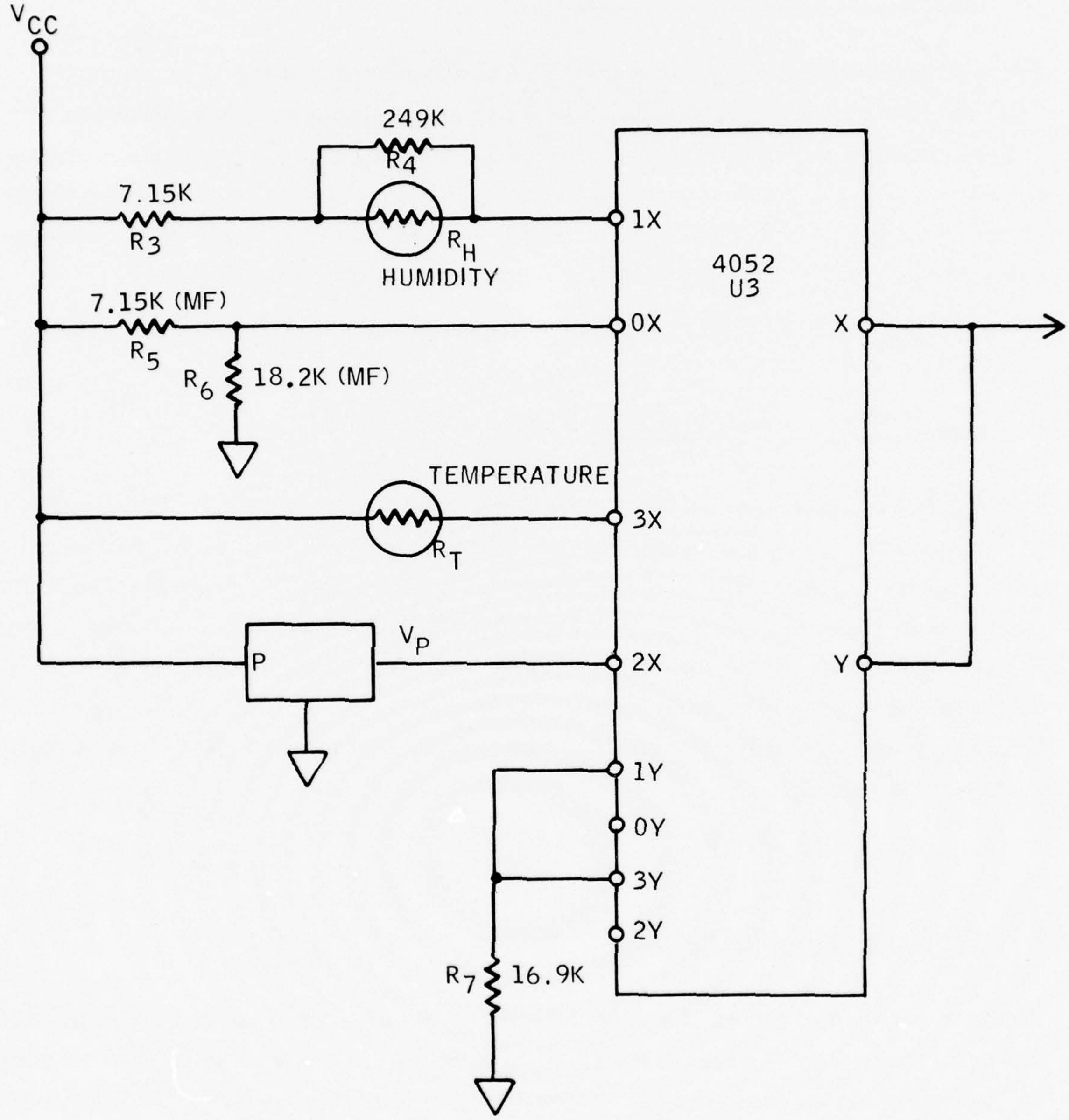


Figure 43. Sensor Input Network Circuit Diagram (Detail from Figure 6)

calculated from supply voltage V_{CC}, temperature voltage $[E_o(T)]$ and R_7 with Equation 11:

$$R_T = \frac{16.9K \times V_{CC}}{E_o(T)} - 16.9K \qquad (13)$$

To convert resistance to temperature, the thermistor transfer equation as given in Equation 6 can be used. A nominal thermistor lock-in value of 14,000 ohms was used.

4. Humidity Calculation

Humidity was sensed with a resistive carbon hygristor (R_H) as shown in Figure 43. To calculate humidity, frequency is converted to voltage and the frequency for the hygristor is multiplied by 0.00321 as defined in Equation 11.

The humidity element has a 249,000 ohm ±1 percent resistor connected in parallel and a 7,150 ohm ±1 percent resistor connected in series with the above parallel combination. This configuration provides a humidity input resistance of 256,150 ohms with an open humidity element and 7,150 ohms with a shorted humidity element.

To calculate humidity, it is necessary to determine the resistance of the carbon hygristor separately from the humidity resistance network. The resistance of the hygristor can be determined from Equation 7. From this resistance and the lock-in value, humidity can be determined from Table 3.

5. Altitude Calculation

To calculate altitude above ground from the telemetered frequency requires three steps. First, the frequency signal from the barometer is multiplied by 0.00321 as described in Equation 9. This gives the barometer output voltage V_B. Next, the barometric pressure in millibars can be calculated from Equation 1.

To convert from atmospheric pressure to altitude above ground, Equation 2 is used.

Substituting in Equation 2 for a sea level temperature of 15°C (518°K) and sea level pressure of 1013 millibars, we get Equation 3.

Reducing Equation 3, we get the expression for altitude versus pressure in Equation 4. This equation is the standard aircraft pressure altitude formula which has been validated for the range of this balloon-borne minisonde. This equation does not compensate for individual humidity conditions.

C. FIELD TESTS

To demonstrate the operating performance of the minisonde, three minisondes were launched during the week of 14-17 February at Honeywell's Annapolis operations. These facilities include an outdoor antenna test range which provides a large open area for balloon launching and telemetry reception. A photograph of the test site is shown in Figure 44. The test instrumentation was mounted in the van shown in the center foreground. The telemetry antennas were mounted on top of the wooden tower shown in the center background of the photograph. The telemetry receiver and recording equipment are shown in Figure 45. A parallel system was set up using two separate telemetry antennas, two RF receivers, and signals recorded separately on a four-channel magnetic tape recorder. The test procedure used is described in detail in the field test plan, which is included as Appendix D.

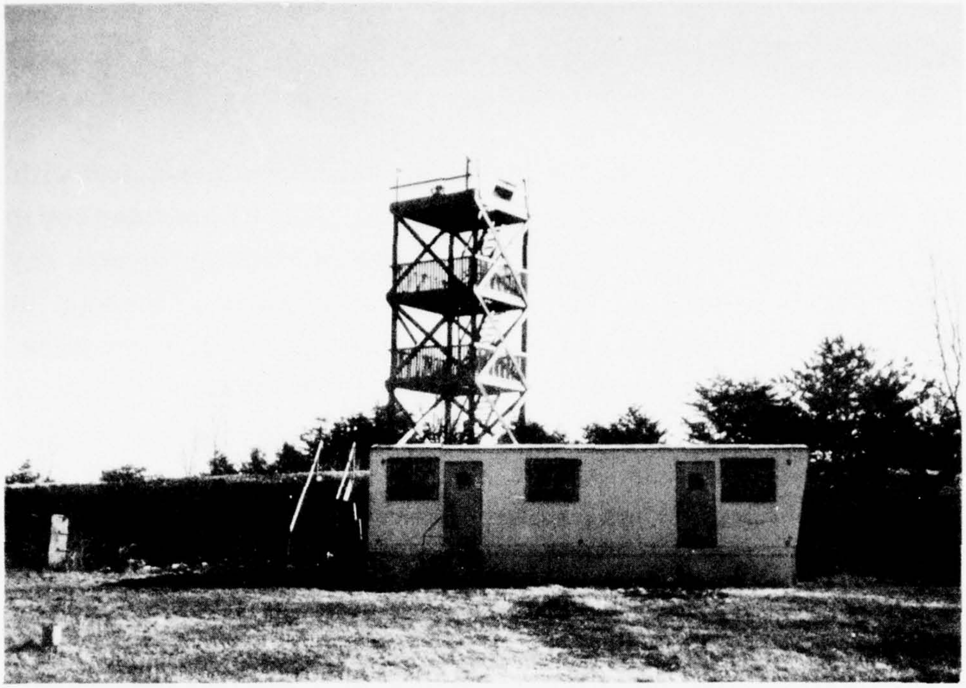


Figure 44. Test Site, Van, and Antenna Tower

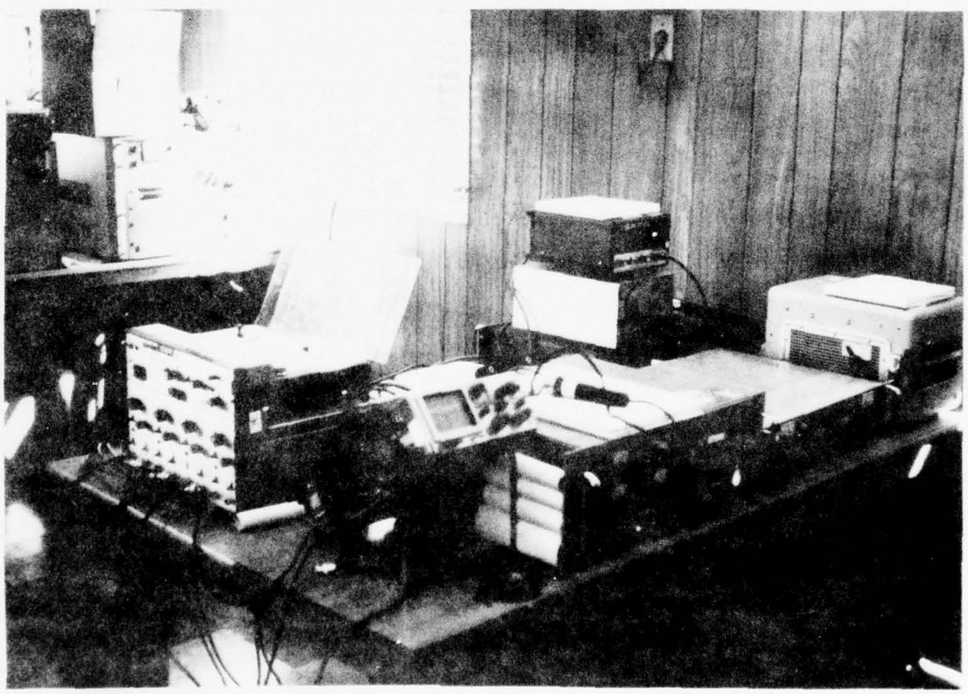


Figure 45. Telemetry Receiver and Recording Equipment in Test Van

In addition to this test equipment, the launch pressure was measured with a Wallace and Tiernan aneroid barometer (Model ML-401/U) provided for us by Mr. S. J. Grillo of NADC. The ambient pressure reading for both days of the test was 1011.2 millibars. The temperature was about freezing, and the wind was about 15-20 miles per hour. The sky was clear; there were no apparent cloud layers during any of the launches. The balloons were filled with helium from tanks used in the welding shop at Honeywell's Annapolis operations. To fill the balloons, each balloon had a 270-gram weight attached to the fill nozzle. The balloon was slowly filled with helium until it had sufficient lift to raise the 270-gram weight off the floor. This provided the proper amount of free lift. The balloons were tied off, carried outside, and tied to the minisonde with a 30-foot length of fish line. The balloon-borne minisonde was released from an open area in the paved parking lot as shown in Figure 46. In spite of the very high wind, it was easy for one person to launch the balloon and minisonde without damaging either of them. The minisonde and balloon in flight, just after launch, are shown in the photograph of Figure 47. The minisonde appeared to be stable in the air. There was no significant coning or swinging.

One telemetry channel consisted of a 403-megahertz dipole antenna made by the Stoddard Company connected by 60 feet of coaxial cable to a Nems-Clark FM telemetry receiver (Model M10037F). The demodulated signal from the receiver was recorded on a Tannberg four-channel 1/4-inch magnetic tape recorder.

D. TEST RESULTS

The flight test data were recorded on 1/4-inch magnetic tapes along with a 1,000-hertz reference signal to compensate for tape recorder speed changes. To calculate the minisonde temperature, humidity, and pressure readings, it is necessary to read the frequency versus time recorded on the tape. Two

Figure 46. Minisonde and Balloon Being Launched

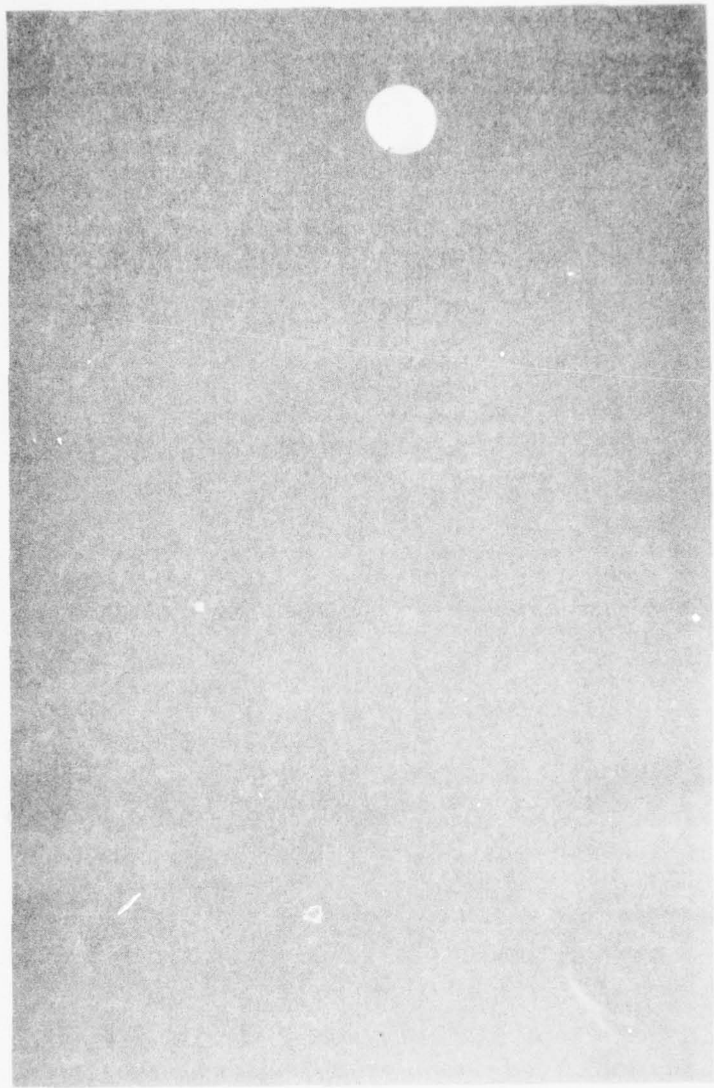


Figure 47. Minisonde and Balloon in Flight

methods were used to read out the frequency data. In the first method, a microprocessor-based decoder developed by Mr. S. J. Grillo of NADC was used to automatically reduce the tape data and plot the results on a strip chart recorder. This readout gave an accuracy of 1-2 percent limited by the accuracy of the recorder and 6-inch printout paper.

A second method of frequency data reading was used at Honeywell. This method used a frequency comparison methodology. The tape recorded data were displayed on an oscilloscope which was synchronized from an external reference oscillator. By adjusting the external oscillator to beat with the recorded signals, it was possible to provide a frequency readout accurate to 1 percent. It was difficult to obtain exact synchronism because the oscillator was commutating between the four signals of high reference temperature, pressure, and humidity. For this operational test, this was adequate, but, in future tests, the data processing should be done with a computer that will provide direct printout of the data; thus, it should be possible to obtain the desired 0.1 percent accuracy.

The temperature and humidity readings versus altitude are shown for the three launches in Figures 48, 49, and 50. Data are only shown for the first 16 minutes of the flight because of battery problems. The lithium/vanadium pentoxide battery that was used in the flights did not maintain its power at low temperatures in this application. After approximately 16 minutes of the flight, the battery voltage had dropped below the linear range of the voltage-to-frequency converter and so the data could no longer be reduced reliably. Even though the battery voltage had dropped off significantly to less than 6 volts, the telemetry transmitter continued to be heard to periods of 45-60 minutes after launch. Data were being received for this whole period of time. As discussed earlier, changes will be made in the minisonde packaging and operation to allow this battery to be used more satisfactorily to obtain the desired 30-minute flight time.

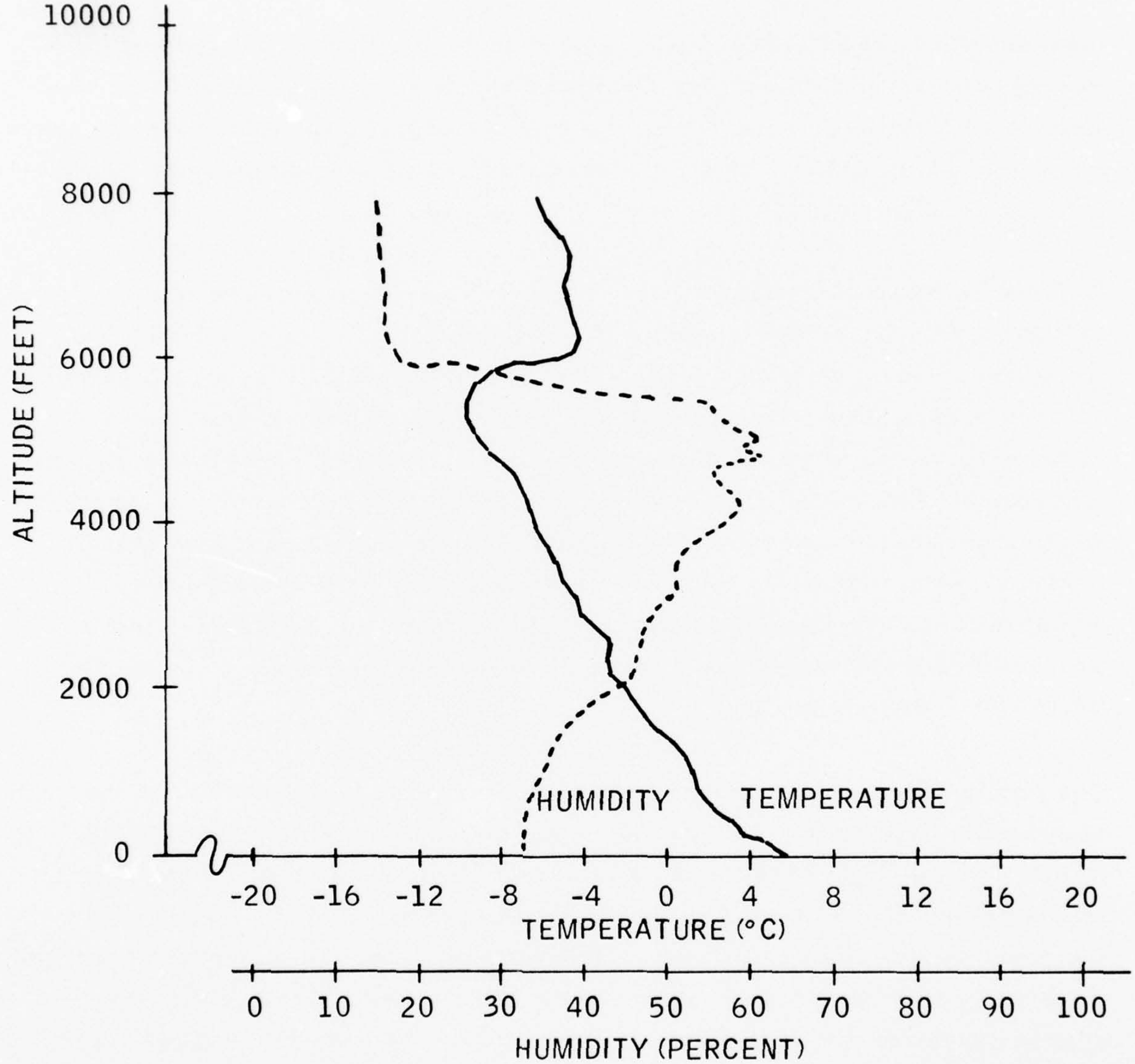


Figure 48. Altitude Versus Temperature and Humidity, Launch 1

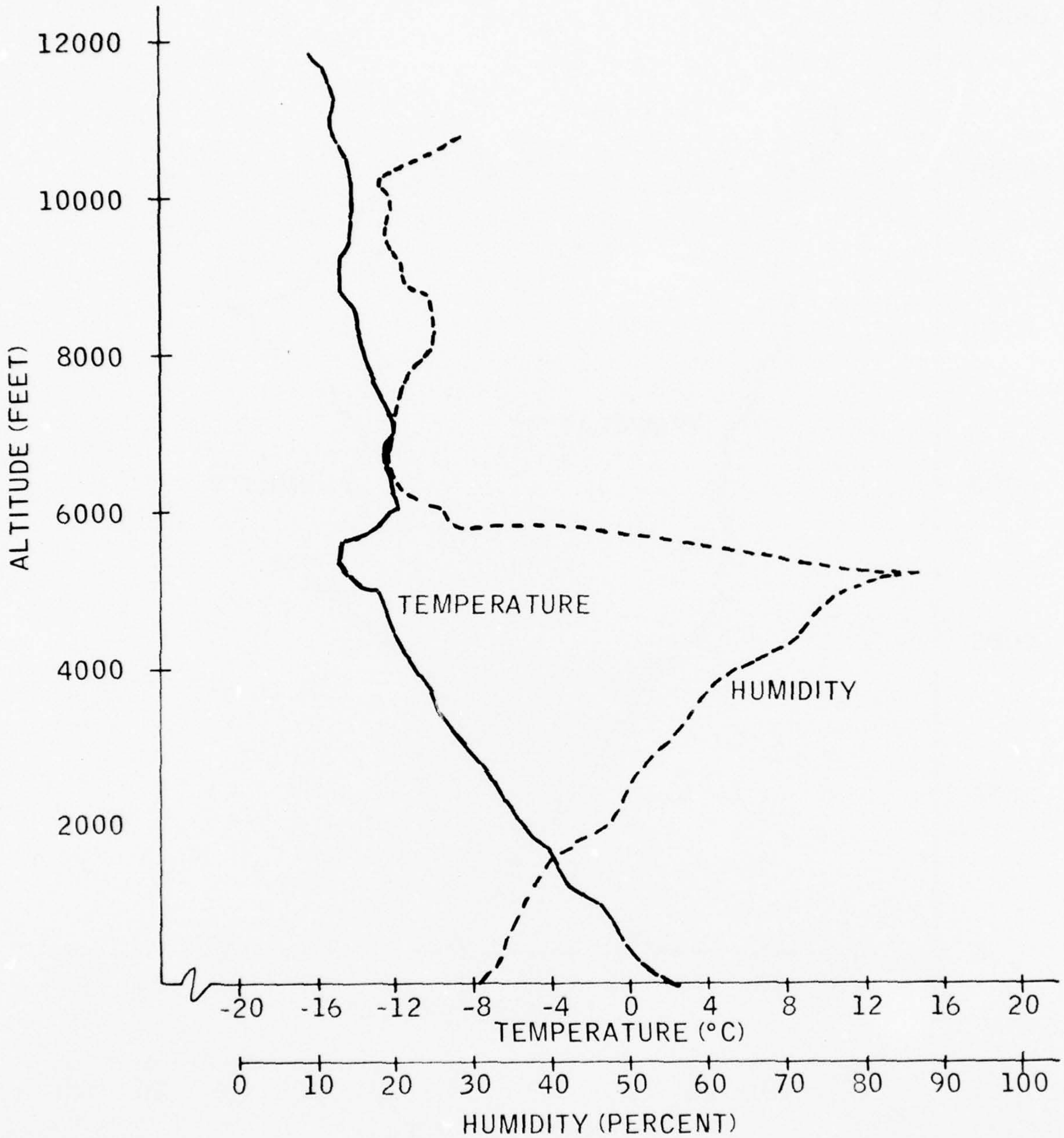


Figure 49. Altitude Versus Temperature and Humidity, Launch 2

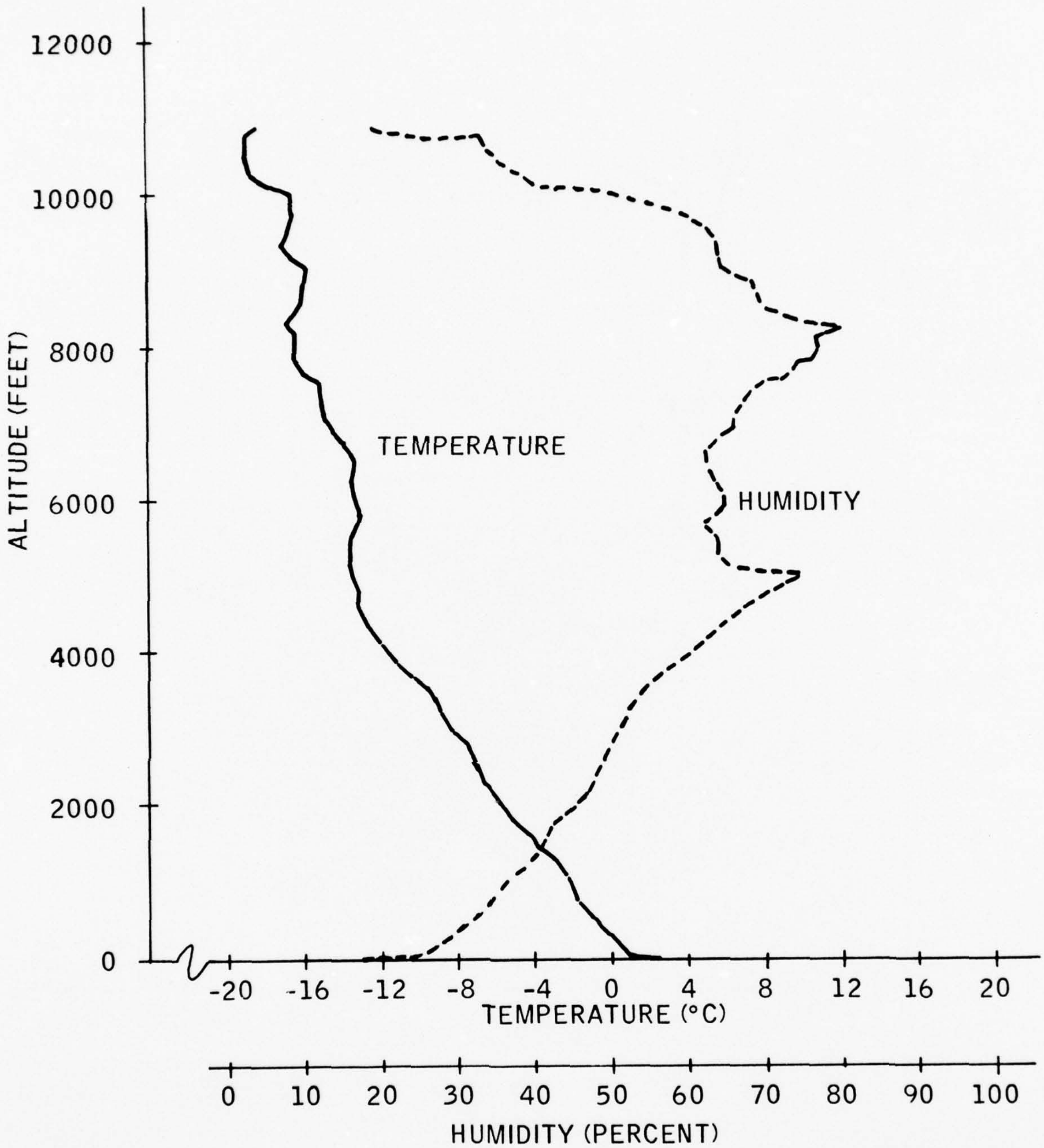


Figure 50. Altitude Versus Temperature and Humidity, Launch 3

Referring to Figure 48, which shows temperature and humidity versus altitude data for the first launch, it appears that there was an inversion layer at about 6,000 feet on that day. This first launch was made late in the morning. In the afternoon, a second launch shown (see Figure 49) also indicated the same inversion layer at 6,000 feet, although it was not as strong of an inversion. The data for the second launch were extended up to 12,000 feet by attempting to compensate for the effect of decreased battery voltage on the voltage-to-frequency converter operation. As in the other two flights, the data above 10,000 feet are quite questionable. This does not indicate that the minisonde stopped ascending at 13,000 feet. Launch 3 (see Figure 50) was made on the morning of the following day, and no inversion is seen. In this flight, the battery dropped off more rapidly than before, so, again, the data beyond the 10,000-foot layer are in question.

E. COMPARISON OF TEST RESULTS WITH DESIRED REQUIREMENTS

1. Temperature

The desired accuracy for temperature is 0.1°C. The accuracy of temperature measurement is determined by three factors - the sensor accuracy at converting from temperature to resistance change, the accuracy of the voltage-to-frequency converter, and, finally, the accuracy of the frequency decoding in the ground station. The accuracy of the temperature sensors are not defined so that sources of error will be excluded. At 0°C, a temperature change of 1°C produces a frequency change of 17 hertz. Based on a full-scale oscillator output of 2,000 hertz, this is just less than 0.1 percent of the frequency range per 1/10°C temperature change. As shown previously, the oscillator accuracy is about 0.1°C using the correction factor to the transfer function to allow for the 0.3 percent curve nonlinearity. Based on these figures, a temperature accuracy of 0.1°C would be difficult. A more achieveable figure would be 0.15-0.2°C.

2. Pressure Accuracy

The desired pressure accuracy is 1 millibar. The overall minisonde accuracy is determined by two factors; the accuracy of the barometer at converting from pressure to voltage and, secondly, the accuracy of the voltage-to-frequency converter. The short-term accuracy and hysteresis of of the solid-state barometer have been shown to be less than 0.25 millibar. Based on the barometer measurements, it would appear that the barometer could be calibrated to an accuracy of 1-2 millibars.

One millibar is 0.1 percent of the total range of 1,000 millibars. The voltage-to-frequency converter has an accuracy of 0.1 percent which corresponds to another error of 1 millibar. The combination of these two would indicate a minisonde pressure accuracy of 2-2.5 millibars.

3. Humidity

The desired requirements are for a 5 percent relative humidity accuracy. Since the voltage-to-frequency converter is much more accurate than 5 percent, most of the accuracy will be determined by the carbon hygristor itself. Five percent should be an achieveable accuracy for the hygristor.

4. Battery

The desired requirements are for a battery that will power the minisonde for a flight of up to 30 minutes. During the flight tests, a battery life of 15 minutes was achieved. In Section II.E, several modifications were suggested such as the addition of a fifth cell to the battery, warming the battery by a small heater, and modifying the circuit to tolerate lower end of life voltage. These modifications would improve the battery life. The battery curves indicate that these modifications will give a minisonde operating lifetime of greater than 30 minutes.

5. Transmitter Requirements

The desired requirements for the transmitter are that the transmitter telemeter reliable data over a range of 25 miles. Based on the calculations in Section II. D, a range of 25 miles is readily achievable. In the field tests, a steady telemetry transmission was received for 30-60 minutes. Based on a launch wind velocity of about 20 miles per hour and the probability of higher wind velocities at altitude, this would indicate an operating range of 10 or 15 miles, even with the severely reduced battery voltage. The reduced voltage would have reduced the transmitter power output by 6 decibels or more. These tests would indicate that a range of 25 miles is achievable with this transmitter.

6. Balloon Requirements

The desired requirements are for a balloon which, when inflated to a diameter of 30 inches, will rise with the minisonde attached at a rate of 1, 000 feet per minute and will reach an altitude of 20, 000 feet or greater. To illustrate the balloon and minisonde ascent rate, altitude versus time data for each of the three minisonde launches are plotted in Figures 51, 52, and 53. These show an ascent rate of 500-700 feet per minute. This would indicate that the balloon and minisonde are capable of an ascent rate of approximately 600 feet per minute. These curves show that the minisonde ascended about 10, 000 feet in the first 15 minutes of flight since data were received for 30 minutes or more. This would indicate that the minisonde continued on to 20, 000 feet or better. Thus, the maximum minisonde height should be greater than 20, 000 feet.

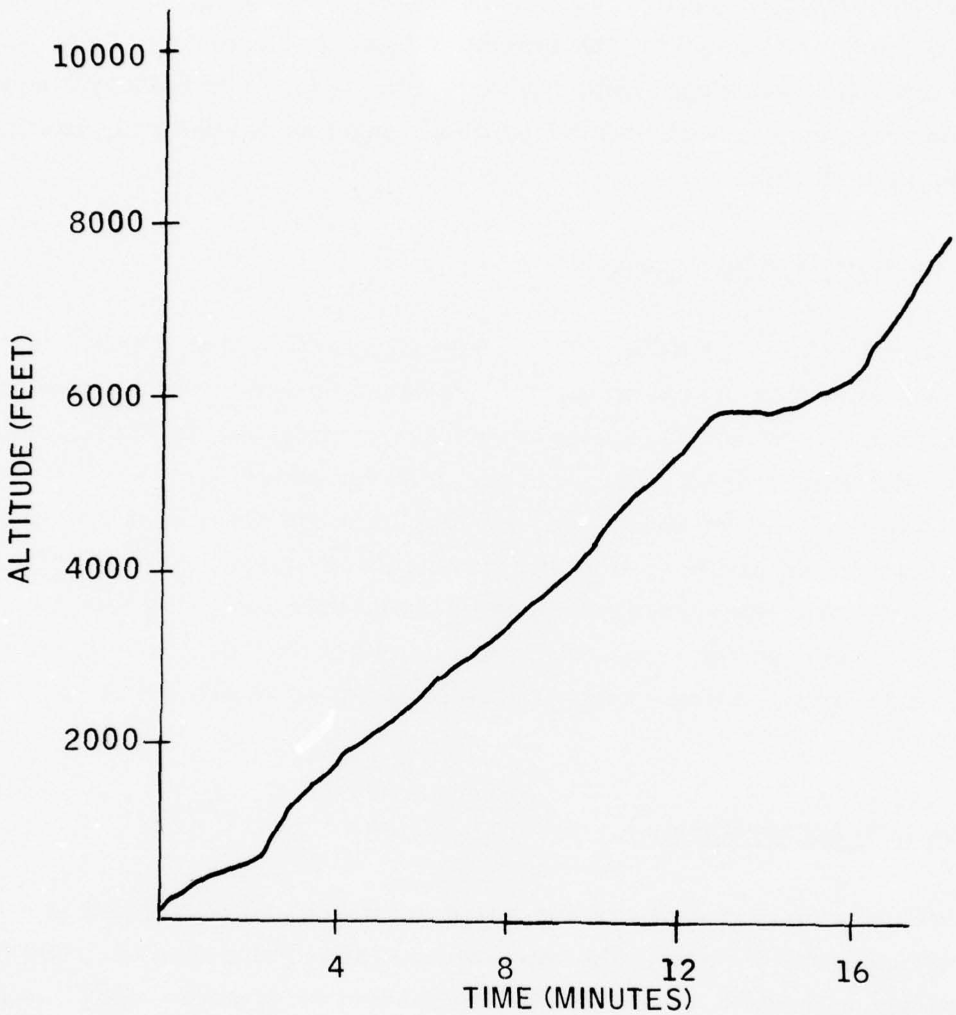


Figure 51. Altitude Versus Time, Launch 1

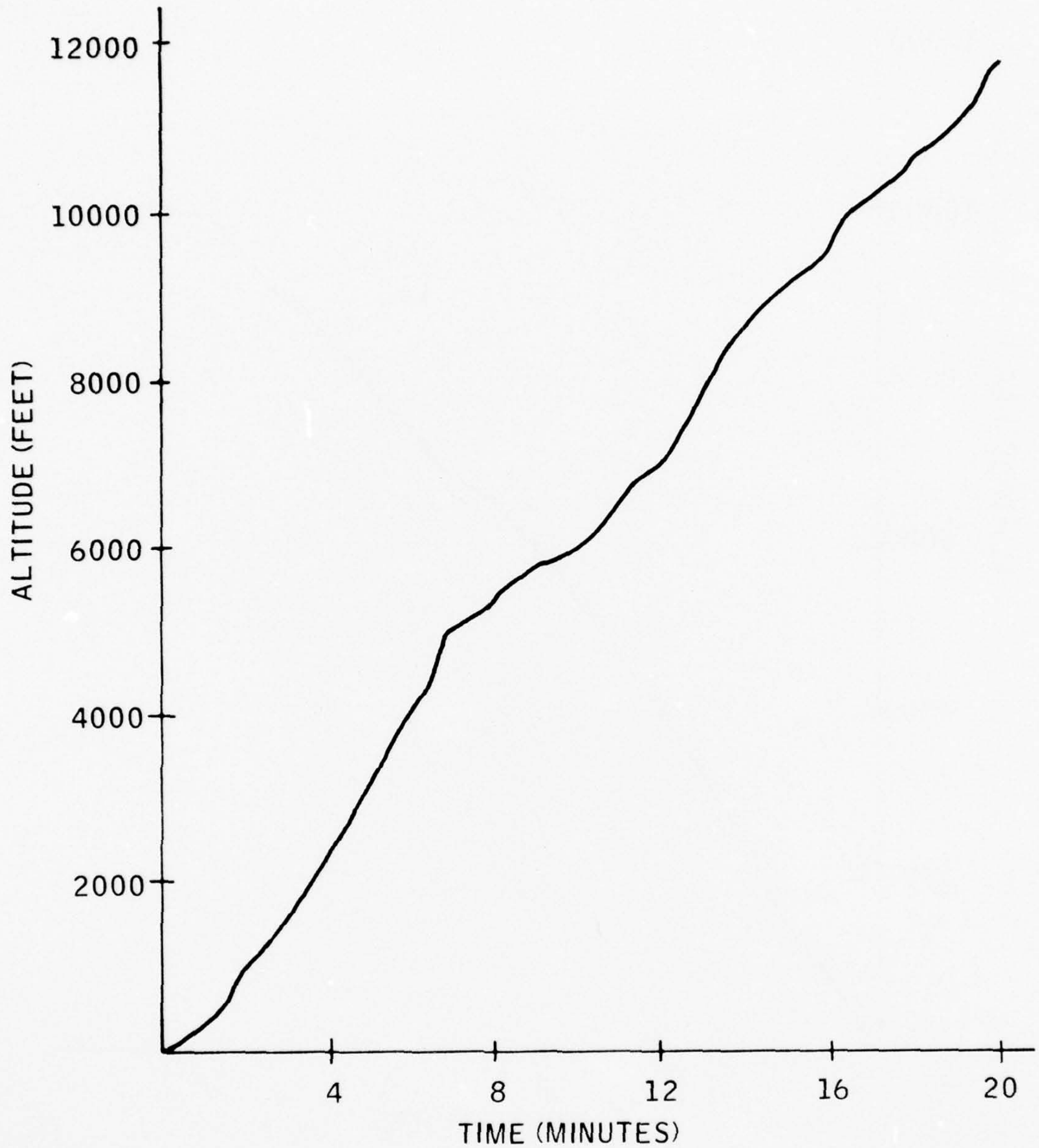


Figure 52. Altitude Versus Time, Launch 2

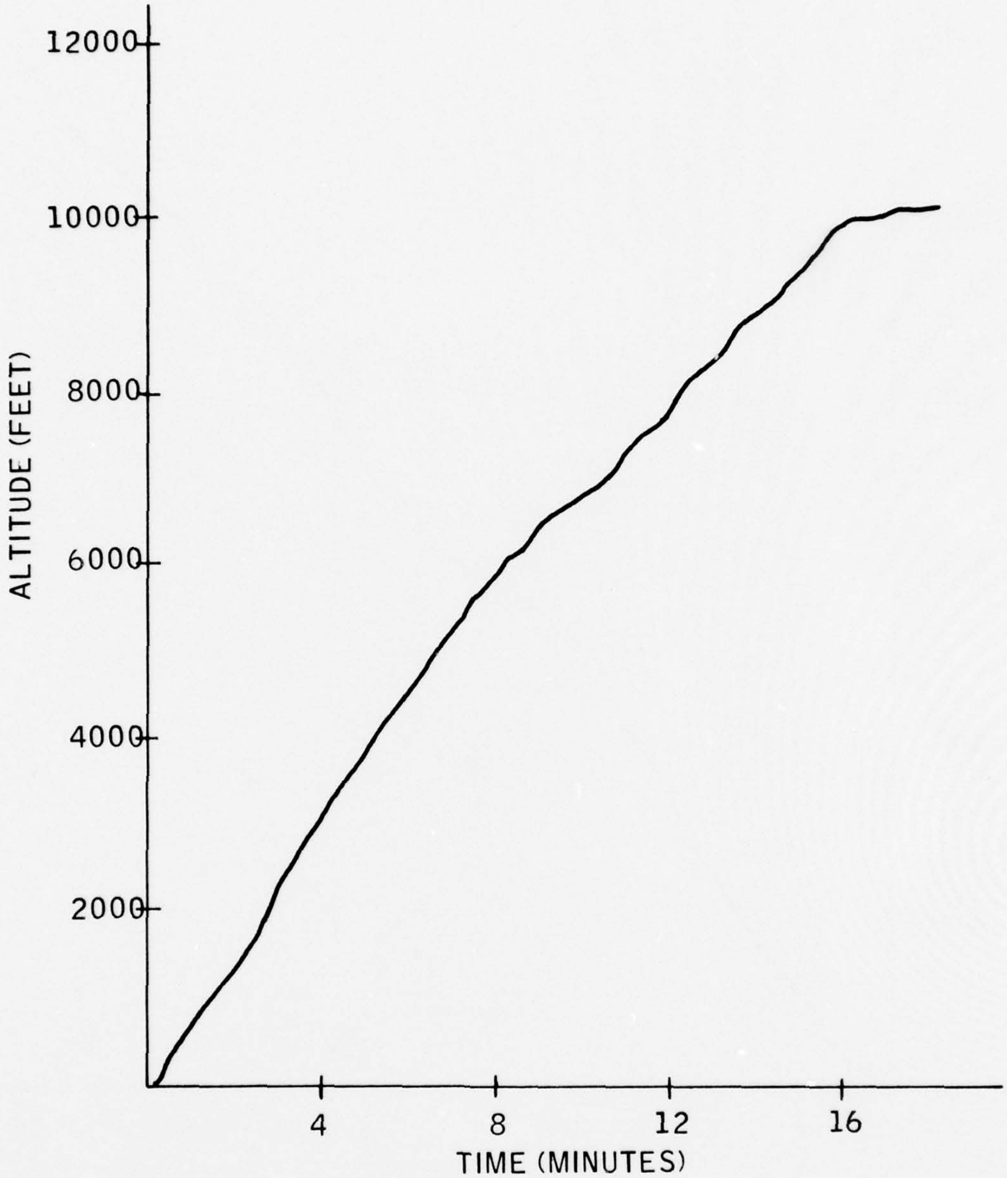


Figure 53. Altitude Versus Time, Launch 3

7. Package

The desired requirements for a package to house the minisonde require that the package provide adequate air flow for the sensors and include radiation and range shielding. The package should be easy to handle and provide physical protection for the sensors, and the maximum weight of the package including the balloon should be 100 grams. The minisonde provides air flow to the sensors equivalent to the present heavier radio wind (rawin) sondes. The cover provides radiation and rain shielding for the humidity sensor and pressure sensor. For this concept demonstration, the temperature sensor was exposed to direct sunlight radiation, which is consistent with present sonde practice. In the final design, radiation shielding will be provided. The minisonde package is small, but rugged enough to withstand a 3-foot drop. Each of the sensors is covered or surrounded by physical shielding. The weight of the minisonde is 86 grams including battery. With a 30-gram balloon, the total balloon train weight is 116 grams.

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of these first models and tests, a minisonde can be constructed which will have the following characteristics:

- Temperature measurement accuracy - 0.25° C.
- Pressure measurement accuracy - 2.5 millibars.
- Humidity accuracy - 5 percent relative humidity.
- Battery life - 30 minutes.
- Telemetry range - 25 miles.
- Balloon ascent rate - 600 feet per minute.
- Maximum altitude - >20,000 feet.
- Minisonde weight excluding balloon - 86 grams.

This program has demonstrated that it is possible to build a small, light-weight minisonde for use in index of refraction measurements. The balloon for this minisonde is small enough that it can be filled within a room and carried out through a standard door. The main purpose of this program was to demonstrate that, using modern technology, a small, light-weight balloon-borne minisonde could be assembled in practical hardware. This objective has been accomplished.

The conceptual development has been completed; however, there are several tasks that need to be accomplished before a finished minisonde is ready for production. Full scale models must be developed which require further effort. More work must be done on the battery to obtain the desired 30-minute operating lifetime. The package should be redesigned to reduce its weight and increase its strength. The present package requires too much manual labor for assembly so the package should be designed for easy assembly. Additional design is required to provide the maximum sensor and encoding accuracy.

APPENDIX A

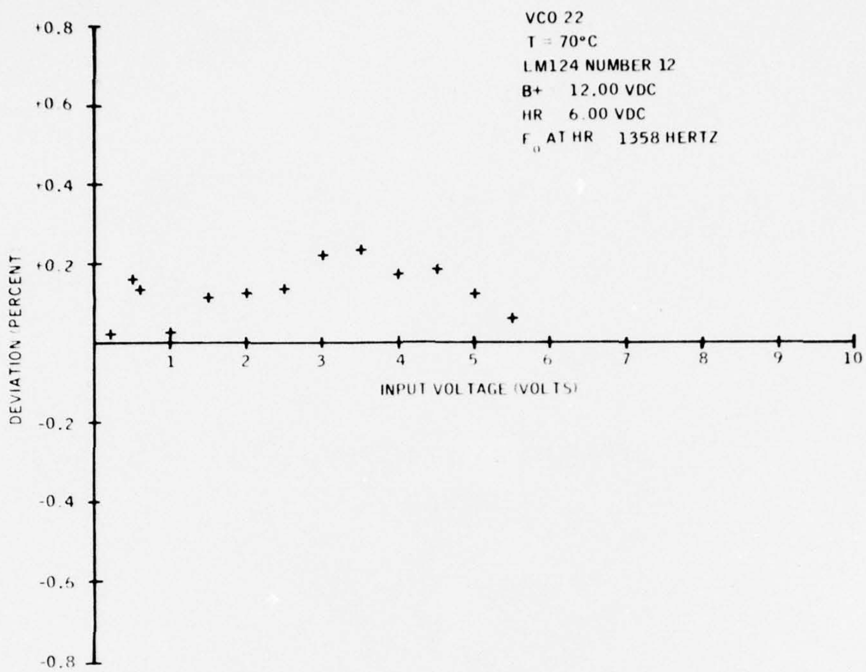
INTEGRATED CIRCUIT VCO TEST DATA

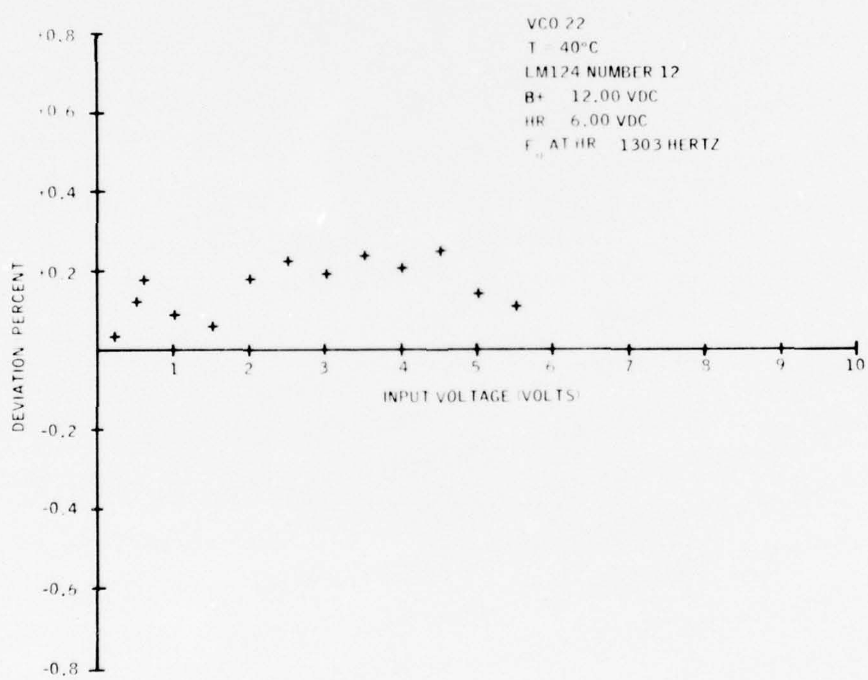
AD-A043 300 HONEYWELL INC HOPKINS MINN DEFENSE SYSTEMS DIV F/G 4/2
MINIATURE METEOROLOGICAL BALLOONSONDE.(U)
JUN 77 C MOTCHENBACHER N62269-76-C-0368

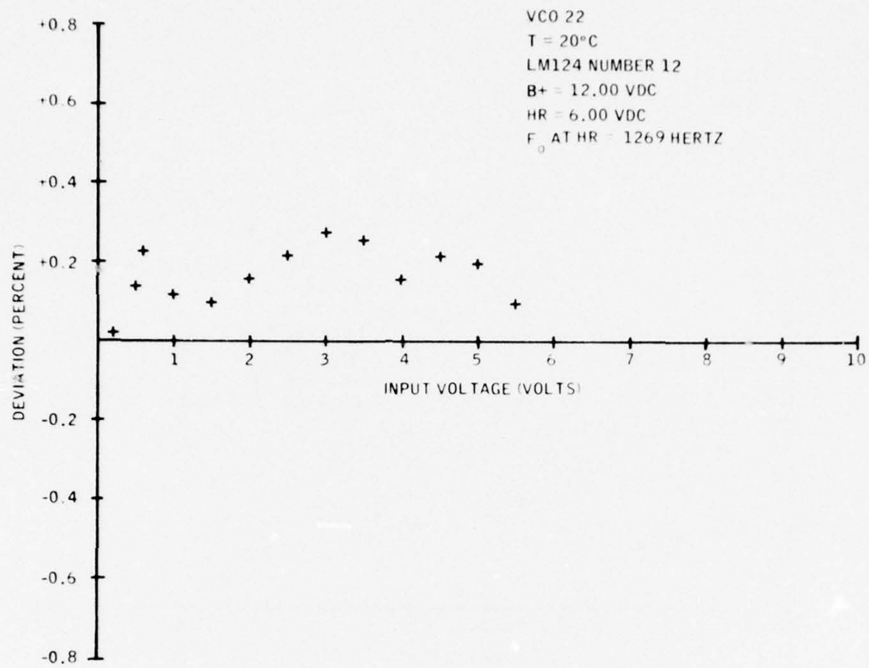
UNCLASSIFIED NADC-76129-30 NL

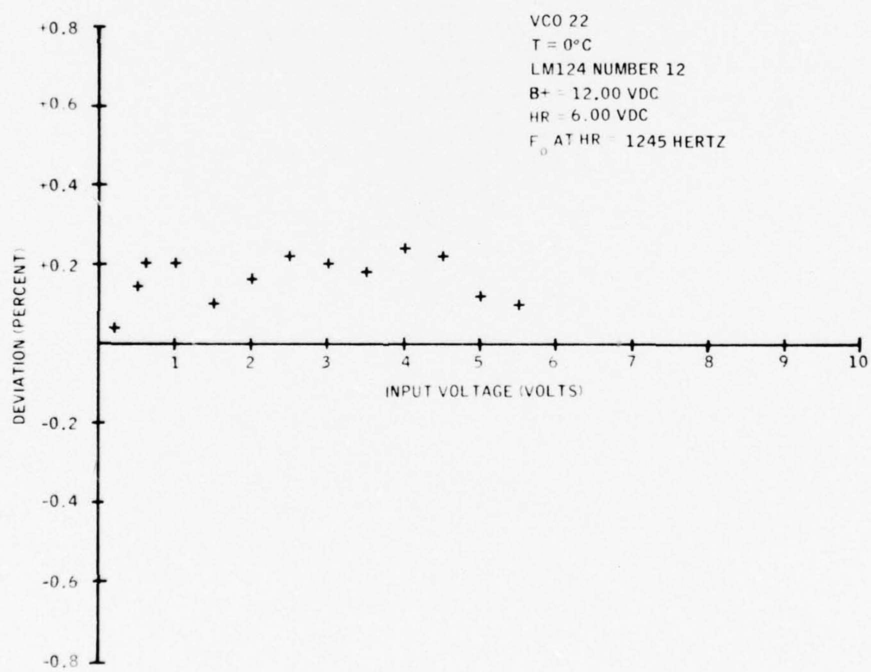
2 OF 2
AD:
A043300

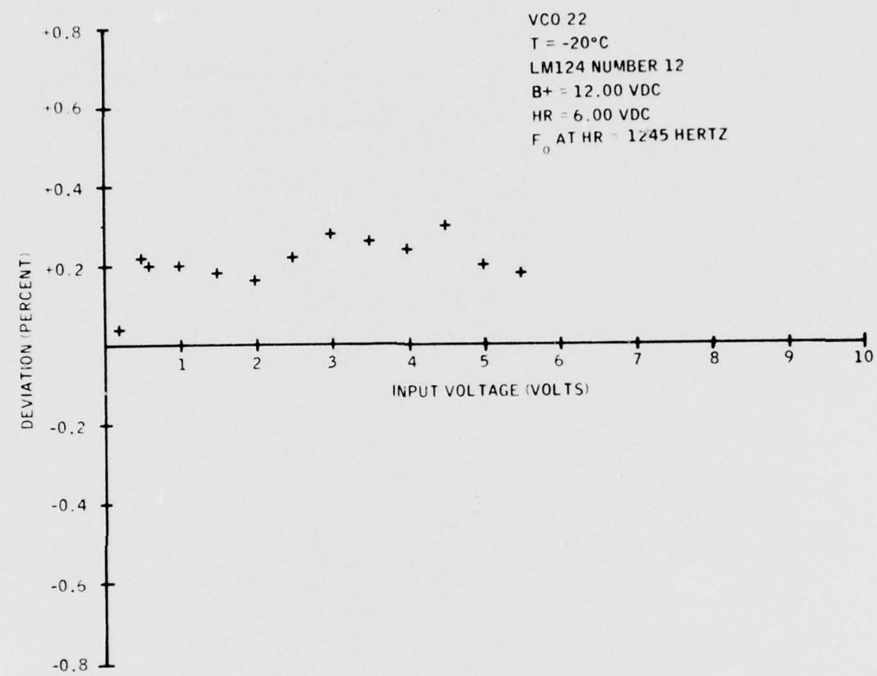
END
DATE
FILMED
9-77
DDC

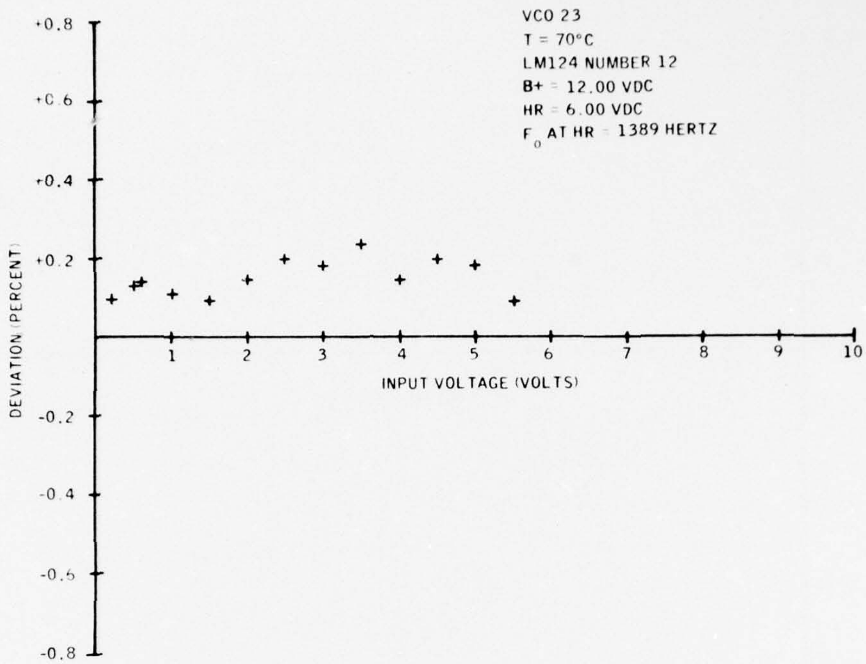

VCO 22
T = 70°C
LM124 NUMBER 12
B+ 12.00 VDC
HR 6.00 VDC
F AT HR 1358 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
DEVIATION PERCENT
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)

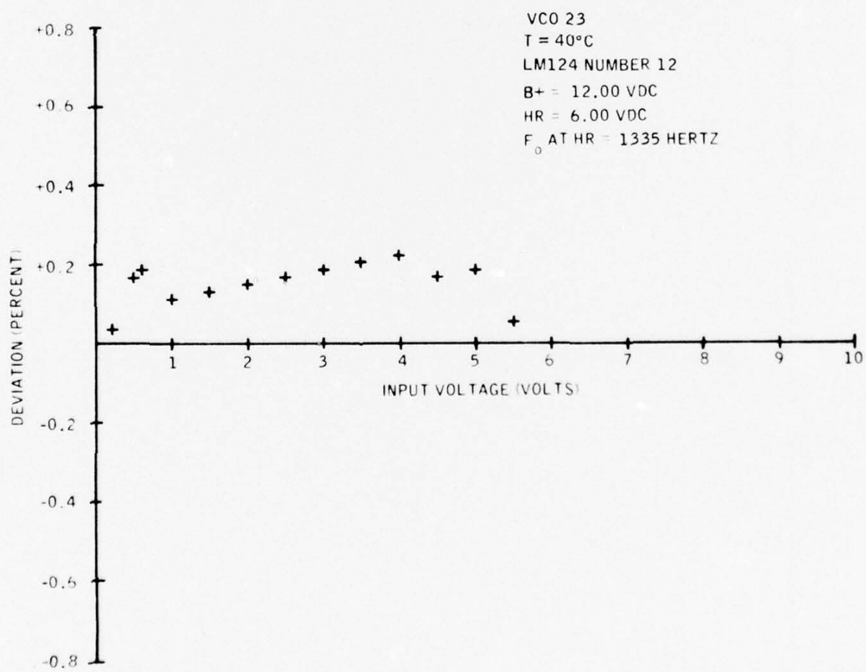

VCO 22
T = 40°C
LM124 NUMBER 12
B+ 12.00 VDC
HR 6.00 VDC
F AT HR 1303 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
DEVIATION PERCENT
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)

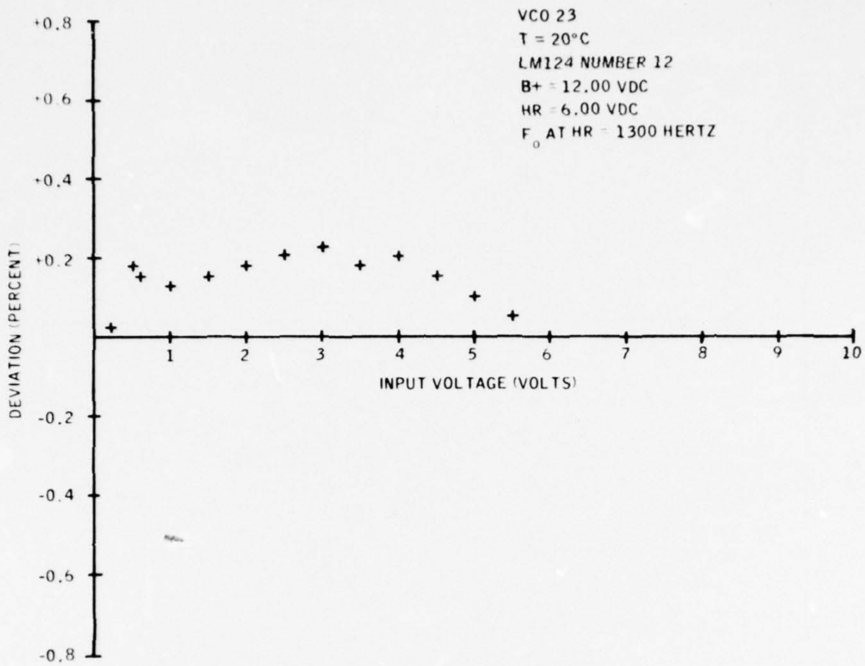

VCO 22
T = 20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1269 HERTZ
DEVIATION (PERCENT)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)

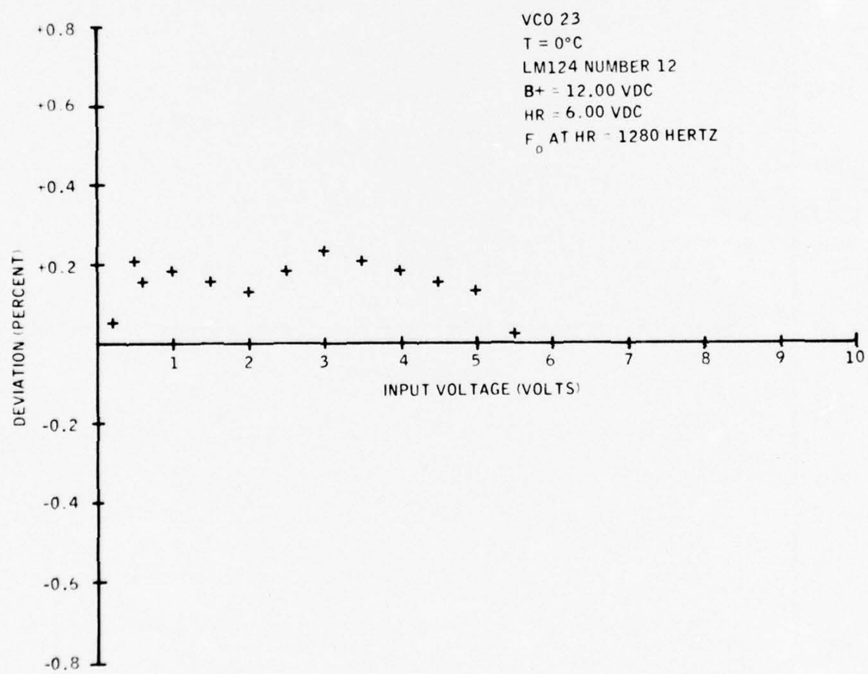

VCO 22
T = 0°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1245 HERTZ
DEVIATION (PERCENT)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)

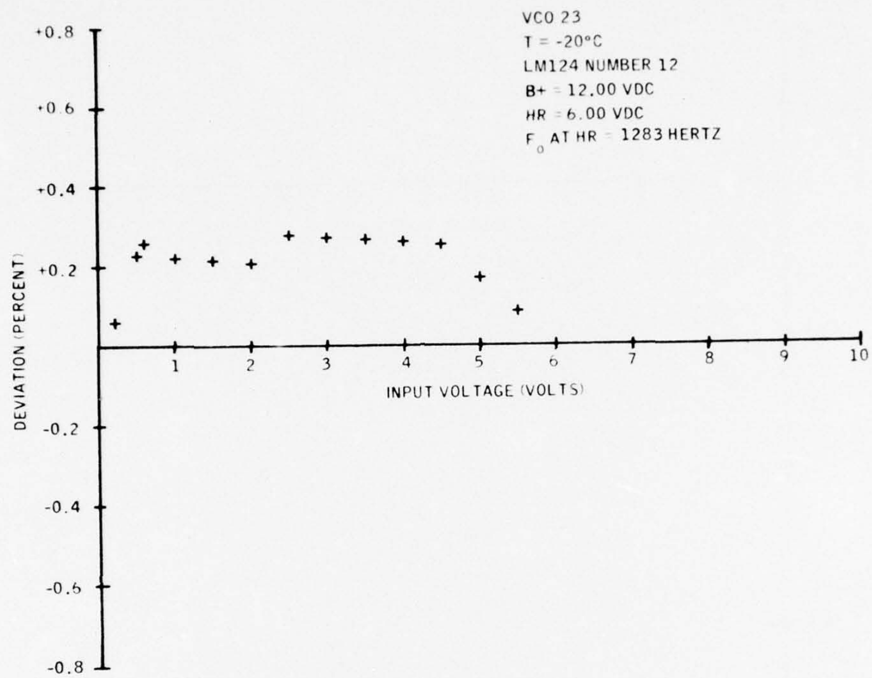

VCO 22
T = -20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1245 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10

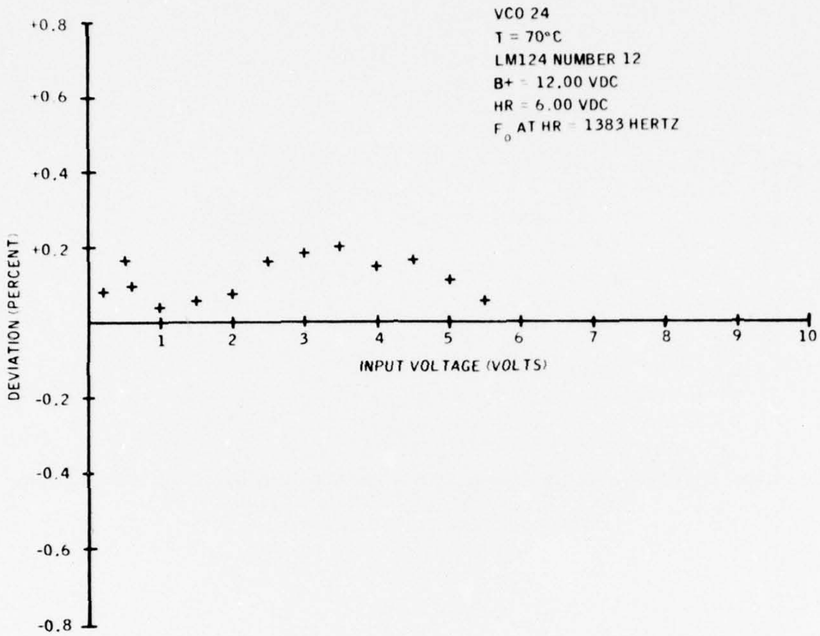

VCO 23
T = 70°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1389 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)

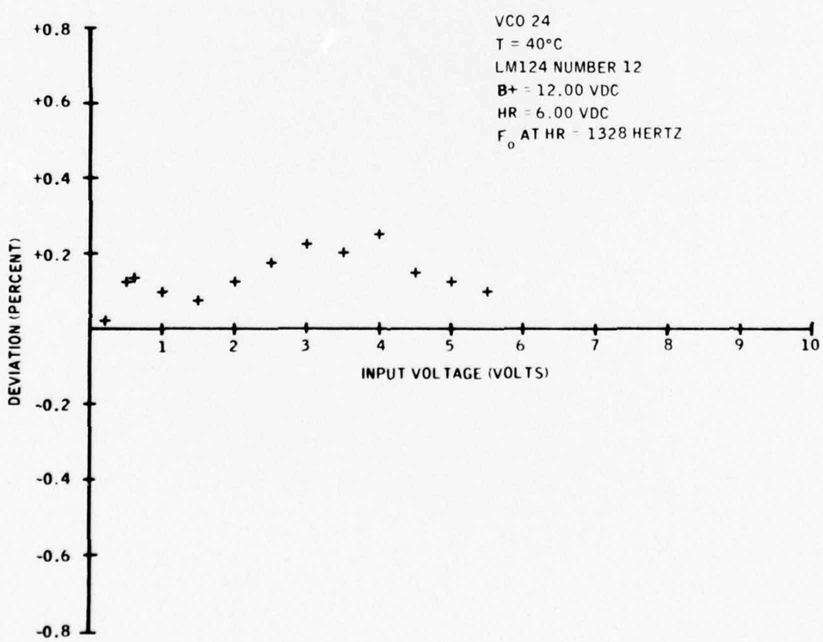

VCO 23
T = 40°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1335 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)

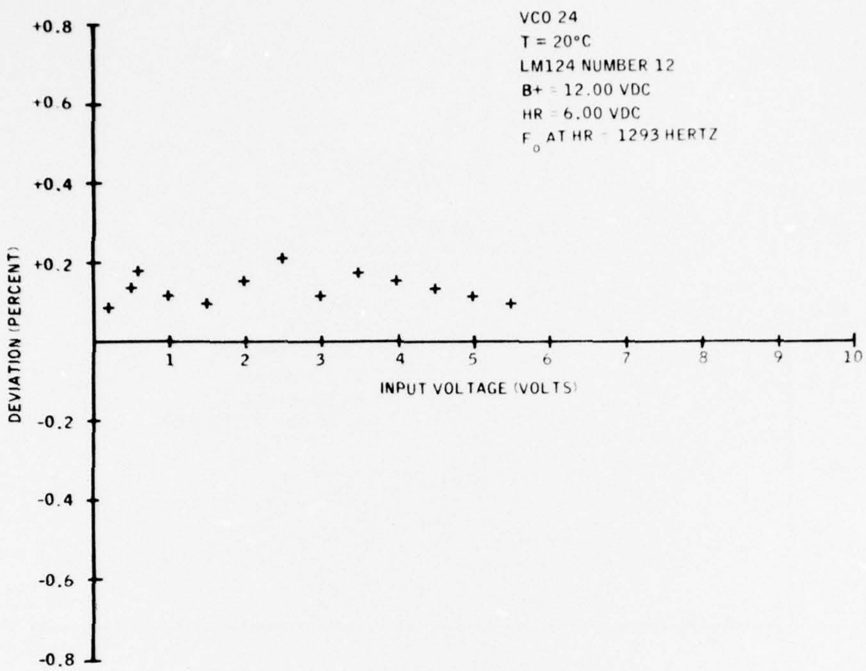

VCO 23
T = 20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1300 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1 2 3 4 5 6 7 8 9 10

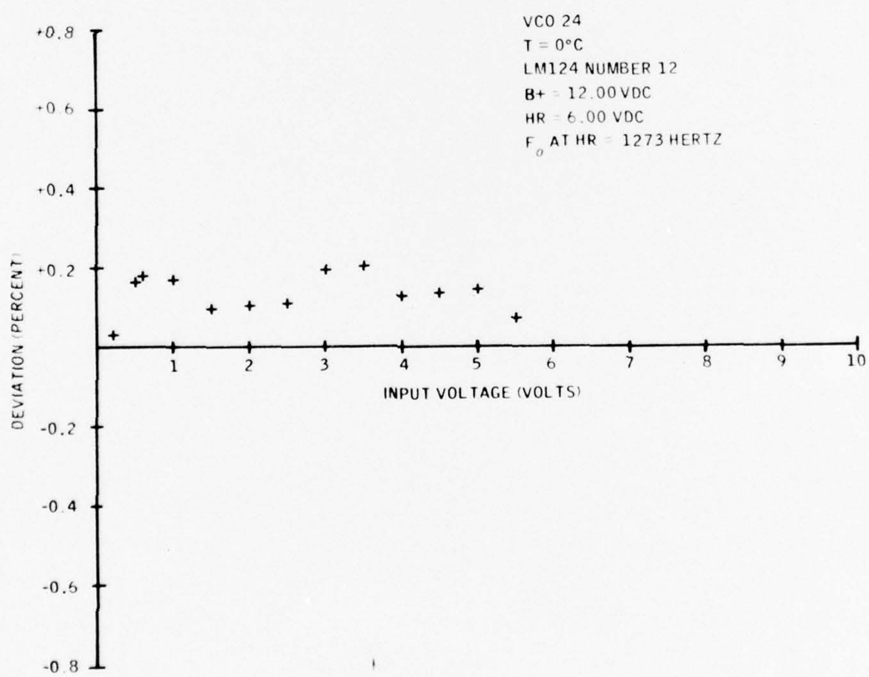

VCO 23
T = 0°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1280 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1 2 3 4 5 6 7 8 9 10

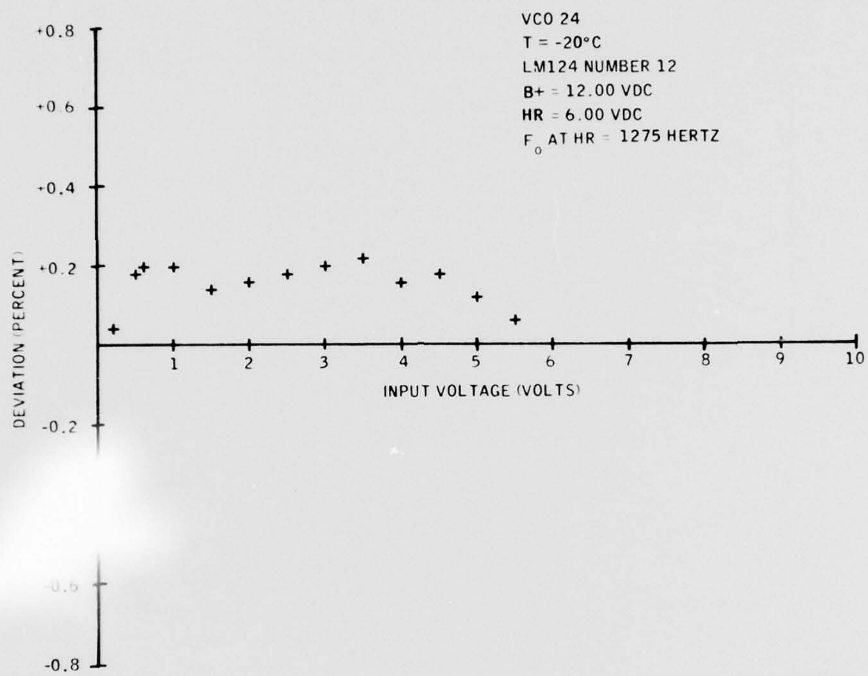

VCO 23
T = -20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1283 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
DEVIATION (PERCENT)
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)

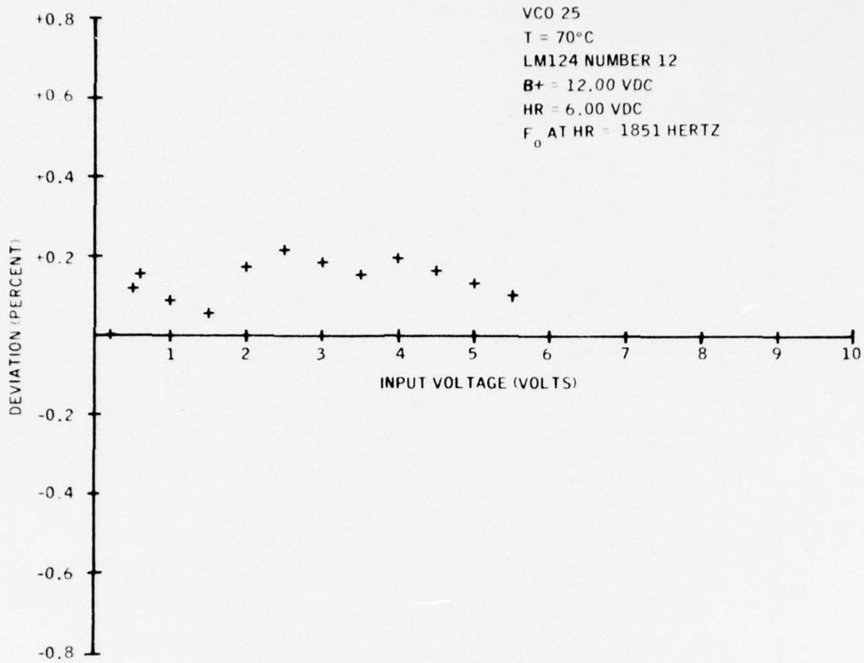

VCO 24
T = 70°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1383 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
DEVIATION (PERCENT)
1 2 3 4 5 6 7 8 9 10
INPUT VOLTAGE (VOLTS)

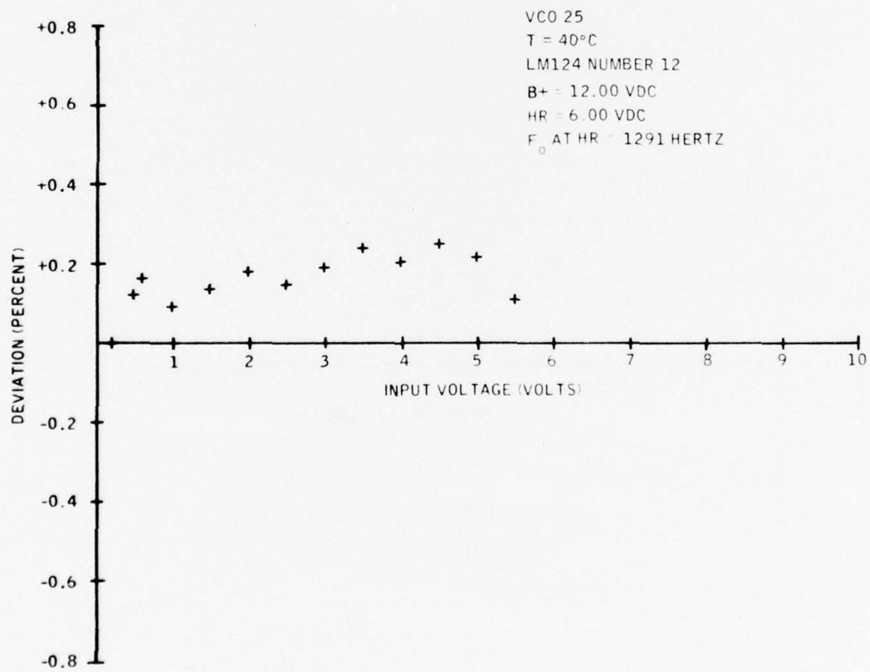

VCO 24
T = 40°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1328 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
DEVIATION (PERCENT)
1 2 3 4 5 6 7 8 9 10
INPUT VOLTAGE (VOLTS)

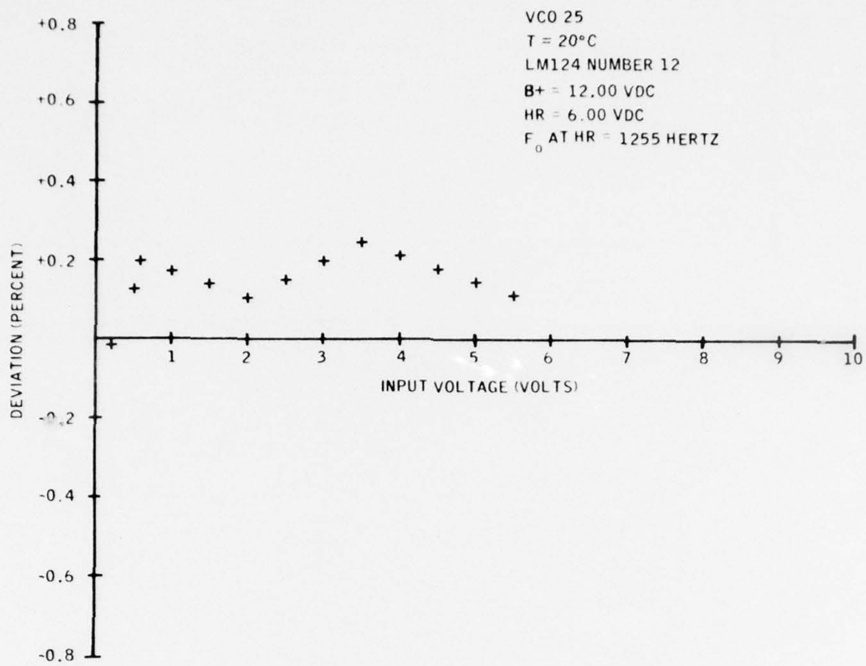

VCO 24
T = 20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1293 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10

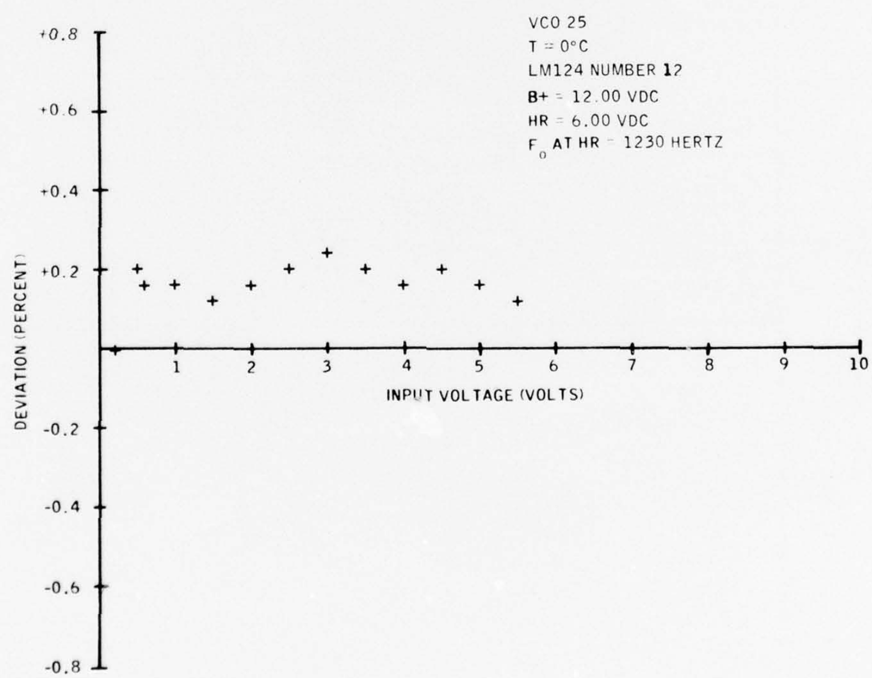

VCO 24
T = 0°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1273 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10

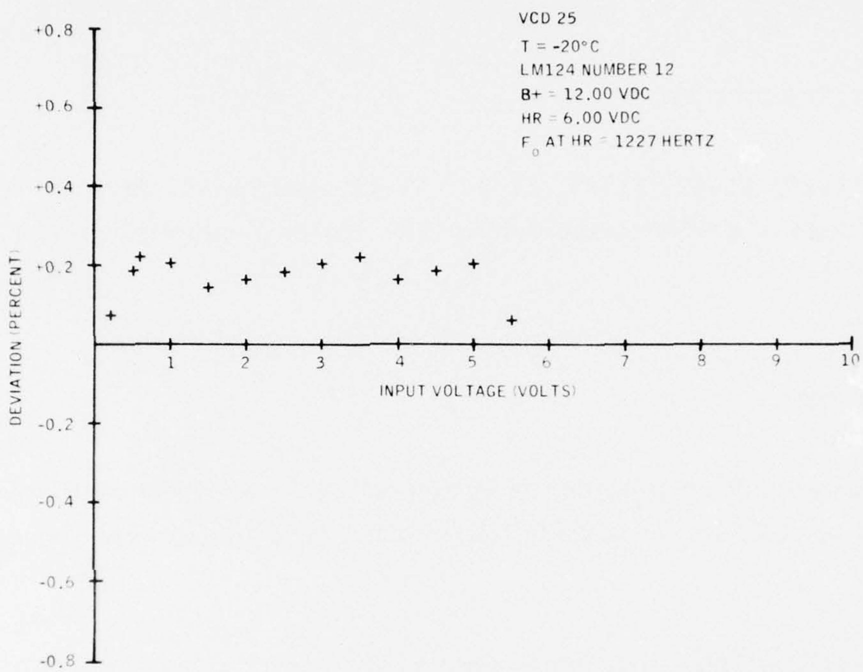

VCO 24
T = -20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1275 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.6
-0.8
DEVIATION (PERCENT)
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)


VCO 25
T = 70°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1851 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)


VCO 25
T = 40°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1291 HERTZ
DEVIATION (PERCENT)
INPUT VOLTAGE (VOLTS)


VCO 25
T = 20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F_0 AT HR = 1255 HERTZ
DEVIATION (PERCENT)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)


VCO 25
T = 0°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F_0 AT HR = 1230 HERTZ
DEVIATION (PERCENT)
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)


VCD 25
T = -20°C
LM124 NUMBER 12
B+ = 12.00 VDC
HR = 6.00 VDC
F0 AT HR = 1227 HERTZ
+0.8
+0.6
+0.4
+0.2
-0.2
-0.4
-0.6
-0.8
DEVIATION (PERCENT)
1
2
3
4
5
6
7
8
9
10
INPUT VOLTAGE (VOLTS)

APPENDIX B

PERFORMANCE VERIFICATION OF G3004 TYPE CELLS FROM A LOT OF 50 CELLS BUILT 12 NOVEMBER 1976

MATERIAL SUBMITTED

Six cells (11-41, 11-42, 11-47, 11-48, 11-49, and 11-50) were discharged for the purpose of performance verification by the Honeywell Power Sources Center (PSC).

BACKGROUND

A request was made to provide the Honeywell Defense Systems Division (DSD) with 40 cells for an application with the following general requirements:

- A cell suitable to allow a stacked five-cell series connection of a battery weighing less than 20 grams.
- Capability of providing 120-100 milliamperes for 1/2 hour at ambient temperature (present electronics may only require 100 milliamperes).
- Minimum voltage end of life, 10 volts (2.00 volts per cell).

The G3004 cell is a unit most closely meeting the above requirements, although designed to provide a continuous current density of 0.344 milliampere per square centimeter as compared with a maximum current density of 4.13 milliamperes per square centimeter required by the new application.

CONCLUSION

The cells built for this contract are similar in performance behavior to previous G3004 cells and can meet the requirements of the new application with the stack assembly recommendation described below.

PROCEDURE AND RESULTS

To allow easier interconnection of cells by the requestor, a small design modification to the G3004 cell was required. Instead of having the leads protruding from the cell pouch at 90 degrees from one another, it was agreed that having leads protruding from the two opposing narrow ends was more convenient. This was the only modification made. The electrodes were left unchanged (see Figure B-1).

Fifty cells were built and activated (see Table B-1). Of these 50 cells, the first 40 were shipped to DSD on 15 November 1976. The remainder were used for the testing reported herein, including four cells put on storage inside a standard Marvelseal 360 pouch.

Three cells were discharged at an equivalent rate as required by the original G3004 cell. The performance requirements for the previous G3004 cell were as follows:

- Voltage - 6.5 volts nominal (two cells in series)
  4.0 volts cutoff (minimum pulse voltage),
- Current - 5-milliampere maximum continuous operating current
  - 50-milliampere pulse current, 250 milliseconds out of every 4 seconds and 5-10 seconds for alarm signal.

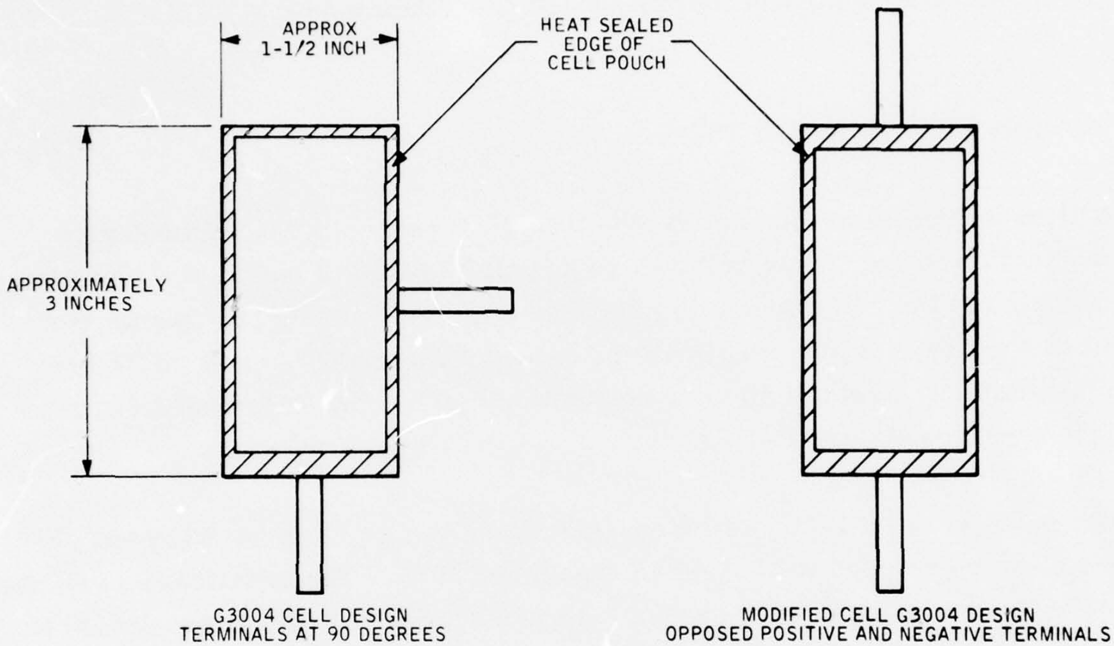


Figure B-1. G3004 Cell Modification

Table B-1. Modified G3004 Cell Open Circuit Voltage Test Data

Cell Number	Open Circuit Voltage (OCV) (Volts)		
	At Activation	After 72 Hours	Quality Control Final Inspection
11-1	3.57	3.49	3.48
11-2	3.64	3.52	3.51
11-3	3.60	3.49	3.49
11-4	3.65	3.52	3.51
11-5	3.62	3.51	3.49
11-6	3.60	3.49	3.48
11-7	3.62	3.49	3.49
11-8	3.65	3.51	3.50
11-9	3.69	3.55	3.55
11-10	3.62	3.51	3.51
11-11	3.66	3.53	3.54
11-12	3.64	3.51	3.51
11-13	3.58	3.46	3.47
11-14	3.61	3.49	3.50
11-15	3.68	3.52	3.53
11-16	3.64	3.51	3.52
11-17	3.60	3.48	3.49
11-18	3.66	3.51	3.51
11-19	3.61	3.49	3.50
11-20	3.62	3.48	3.49
11-21	3.65	3.51	3.50
11-22	3.63	3.51	3.51
11-23	3.64	3.52	3.51
11-24	3.60	3.48	3.48
11-25	3.63	3.51	3.52

Table B-1. Modified G3004 Cell Open Circuit Voltage Test Data (Concluded)

Cell Number	Open Circuit Voltage (OCV) (Volts)		
	At Activation	After 72 Hours	Quality Control Final Inspection
11-26	3.62	3.50	3.50
11-27	3.60	3.49	3.49
11-28	3.65	3.51	3.52
11-29	3.60	3.49	3.48
11-30	3.63	3.51	3.51
11-31	3.59	3.52	3.53
11-32	3.59	3.47	3.48
11-33	3.62	3.49	3.48
11-34	3.65	3.51	3.51
11-35	3.68	3.54	3.54
11-36	3.61	3.50	3.49
11-37	3.62	3.48	3.48
11-38	3.63	3.50	3.51
11-39	3.65	3.54	3.54
11-40	3.58	3.47	3.47
11-41	3.59	3.48	3.48
11-42	3.61	3.47	3.48
11-43	3.60	3.48	3.49
11-44	3.60	3.48	3.48
11-45	3.61	3.51	3.50
11-46	3.62	3.49	3.49
11-47	3.62	3.51	3.51
11-48	3.55	3.47	3.47
11-49	3.60	3.50	3.49
11-50	3.60	3.48	3.46

- Operating Life - 8 hours minimum (12 hours desirable at or above freeqing temperatures).
- Shelf Life - 1 year (design goal) at room temperature.
- Configuration - Maximum thickness = 0. 55 inch. Area = not to exceed 3. 0 inches by 5. 0 inches. As flexible as possible.
- Weight - As light as possible.

The cells discharged against this requirement were run at a constant resistance of 295 ohms at room temperature, which provides 10-milliampere current at 2. 95 volts.

The results are shown below:

Time (Hours)	Voltages Under Load			
	Cell 11-41	Cell 11-42	Cell 11-47	Average of Three Cells
1	3. 23	3. 23	3. 26	3. 24
2	3. 18	3. 13	3. 19	3. 17
3	3. 09	3. 07	3. 14	3. 10
4	3. 07	3. 84	3. 02	2. 98
5	3. 01	2. 37	2. 89	2. 76
6	2. 90	2. 16	2. 75	2. 60
7	2. 67	2. 02	2. 58	2. 41
8	2. 40	1. 89	2. 42	2. 24
9	2. 24	1. 80	2. 26	2. 10
10	2. 19	1. 73	2. 14	2. 02
11	2. 15	1. 66	2. 04	1. 95
12	2. 10	1. 56	1. 88	1. 85
13	2. 04	1. 45	1. 54	1. 68
14	1. 98	1. 34	1. 38	1. 57

Time (Hours)	Voltages Under Load			
	Cell 11-41	Cell 11-42	Cell 11-47	Average of Three Cells
Life in Hours to 2.0 Volts	13.7	7.1	11.3	10.7
Capacity to 2.0 Volts (Ampere-Hours)	0.122	0.068	0.103	0.098
Efficiency in Percent(2[e])	61	34	51	49

The average voltages of the three cells were plotted as shown in Figure B-2.

These cells met the previously established requirements; however, they fell somewhat short of the desired life of 12 hours. Batteries (two G3004 cells in series) built in the past demonstrated a 12-hour capability. The reason for this shortfall is probably due to the slightly lower weights of cathodes in this build as compared to the previous build (0.201 versus 0.237 ampere-hour).

In other words, every 0.01 ampere-hour represents a reduction of about 0.53 hour of discharge time at the above efficiency of 49 percent.

Prorating the results on the basis of capacity results in an average run time of (10.7) (0.237/0.201) = 12.6 hours, as was observed with previously built G3004 cells.

Three cells (see Figures B-3, B-4, and B-5) were discharged to approximate the requirements of this build. Each cell was discharged at a constant resistance of 22.5 ohms. Their discharge times to a cutoff of 2.00 volts ranged from 33 minutes to 18 minutes, with an average of 26 minutes.

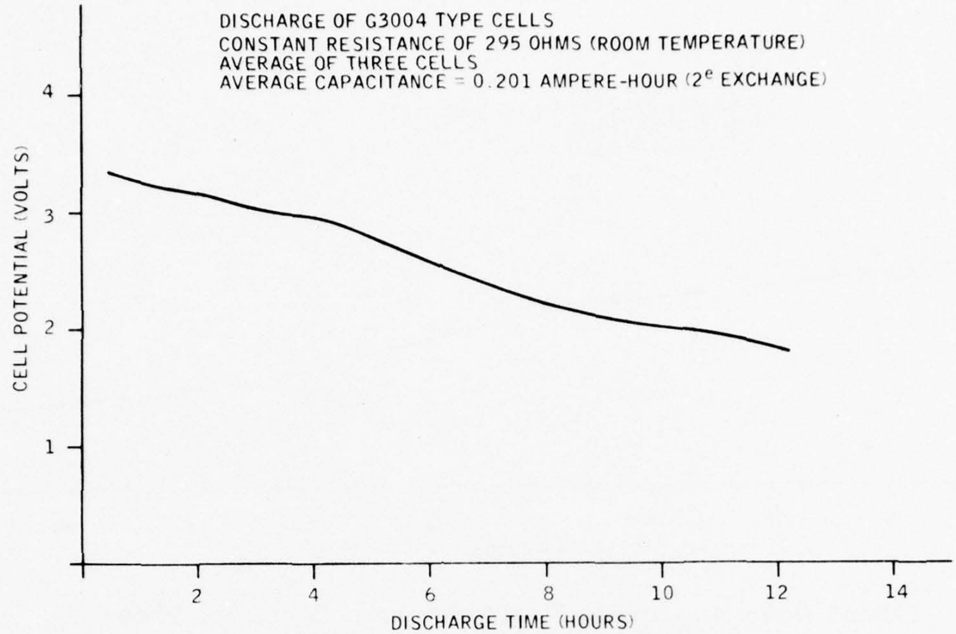


Figure B-2. Discharge Performance of Modified G3004 Cells (Average Voltage of Three Cells)

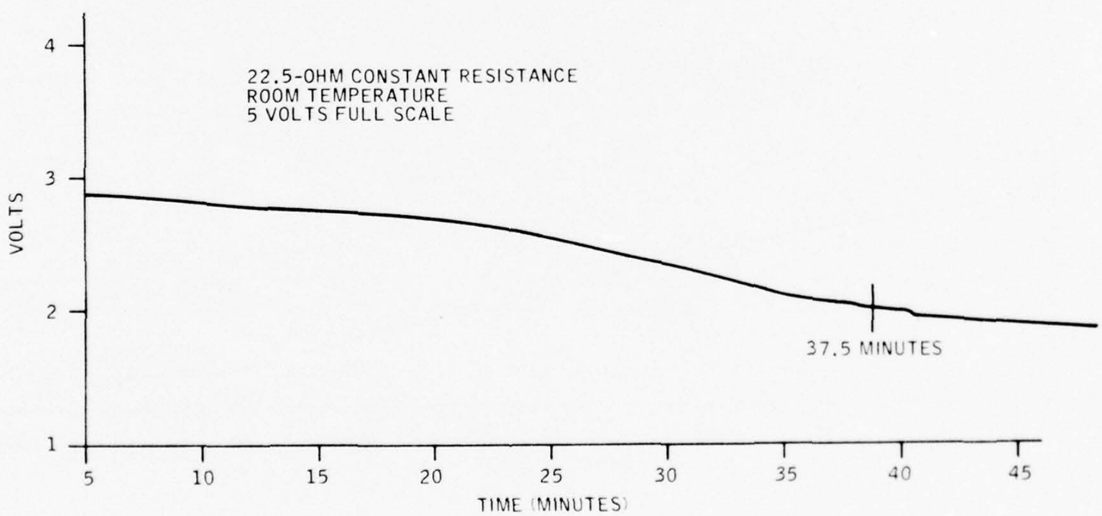


Figure B-3. Discharge Performance of Modified G3004 Cell Serial Number 11-48

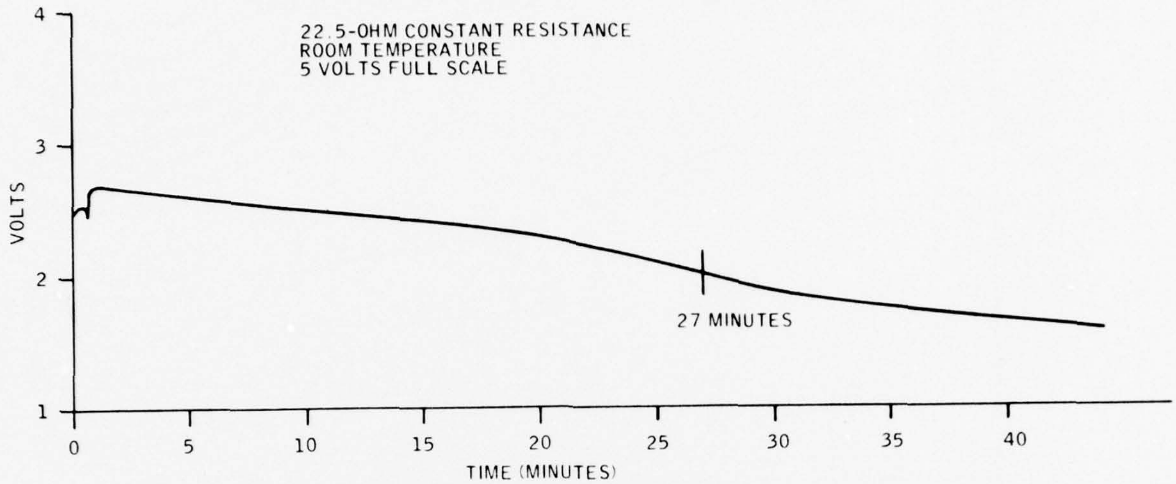


Figure B-4. Discharge Performance of Modified G3004 Cell Serial Number 11-49

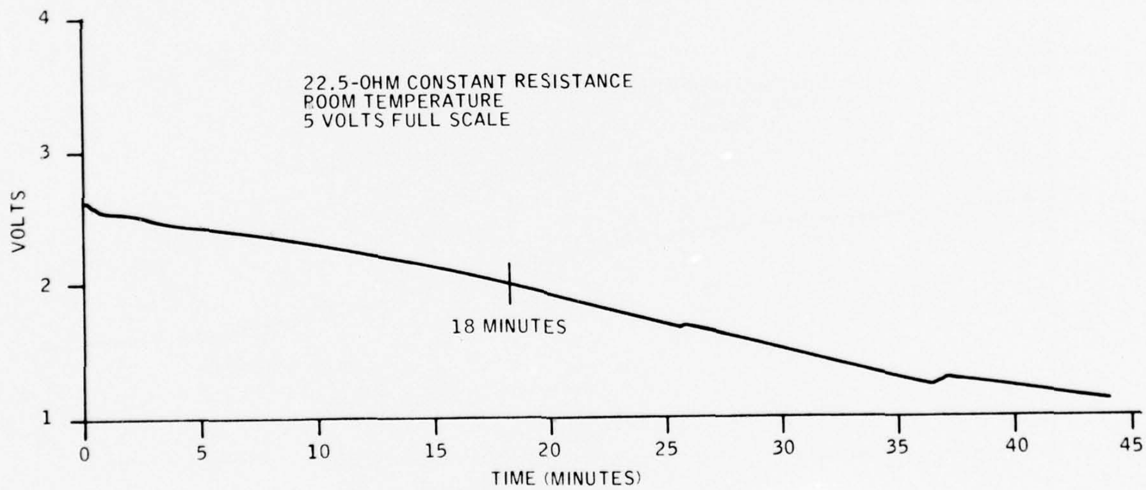


Figure B-5. Discharge Performance of Modified G3004 Cell Serial Number 11-50

It should be noted here that all cells were discharged in an unconstrained condition without any external pressure on the electrodes. Cells of this type are typically sensitive to electrode interface pressure. This becomes more prominent as the current density increases. The application for which this cell lot is to be used requires a current density which is 4.13/0.344 = 12 times as high as for the original G3004 cell design.

It is felt that, when a five-cell stack is assembled from this lot and it is provided with a snugly fitting wrap such as tape, the battery will meet the required discharge time of 1/2 hour.

The weight requirement (less than 20 grams per battery) can only be evaluated in a fully assembled condition; however, the weight of five cells as shipped had a total weight of 17 grams.

APPENDIX C

RETEST OF G3004 TYPE CELLS FROM A LOT OF 50 CELLS BUILT 12 NOVEMBER 1976

MATERIAL SUBMITTED

Four cells (11-31 and 11-32 returned by the Honeywell Defense Systems Division (DSD), and 11-43 and 11-44 retained by the Honeywell Power Sources Center (PSC).

BACKGROUND

Cells 11-31 and 11-32 were returned for evaluation to PSC in the light of cell discharge tests conducted at DSD which showed performance less than cells tested at PSC. A cell is required to have a run time of 30 minutes above 2.00 volts under a load of 24 ohms constant resistance. To these two cells, cells 11-43 and 11-44 were added. These were cells retained from the same build at PSC and stored inside a Marvelseal 360 pouch, as is customary for long-term storage of G3004 cells.

CONCLUSIONS

Two of four cells operated at 28 and 29.9 minutes, respectively, which is comparable to ten results previously obtained by PSC.

One cell operated at 20 minutes which is at the low end of test results previously obtained by PSC.

Results to date indicate that the current required by this application is sufficiently high to affect efficiency and reproducibility.

One cell did not operate - post mortem analysis failed to determine the cause of non-operation.

Open circuit voltage (OCV) readings with time indicated that no decay of the units occurred.

PROCEDURE AND RESULTS

From Figures C-1, C-2, and C-3, representing discharge curves of three cells run at DSD, it can be seen that cell life to 2.00 volts under a load of 24 ohms constant resistance ranged from 15 to 8 minutes, as compared to a run time range of 33 to 18 minutes (22.5-ohm load) observed at PSC.

It is our understanding that the first two cells were discharged in an unconstrained condition, while the cell in Test Number 3 was run with some constraint; however, the compressive force is not known.

In order to duplicate the results obtained at DSD, cells 11-31 and 11-32 were discharged at PSC under a load of 24 ohms constant resistance at room temperature. To these, two additional cells, retained from the same build, were added. These last two cells had been stored in a Marvelseal 360 pouch since 15 November 1976.

All cells were restrained by placing a plastic block having dimensions of 1-7/8 inches x 4 inches centrally on top of each cell face. The block had a weight of 230 grams.

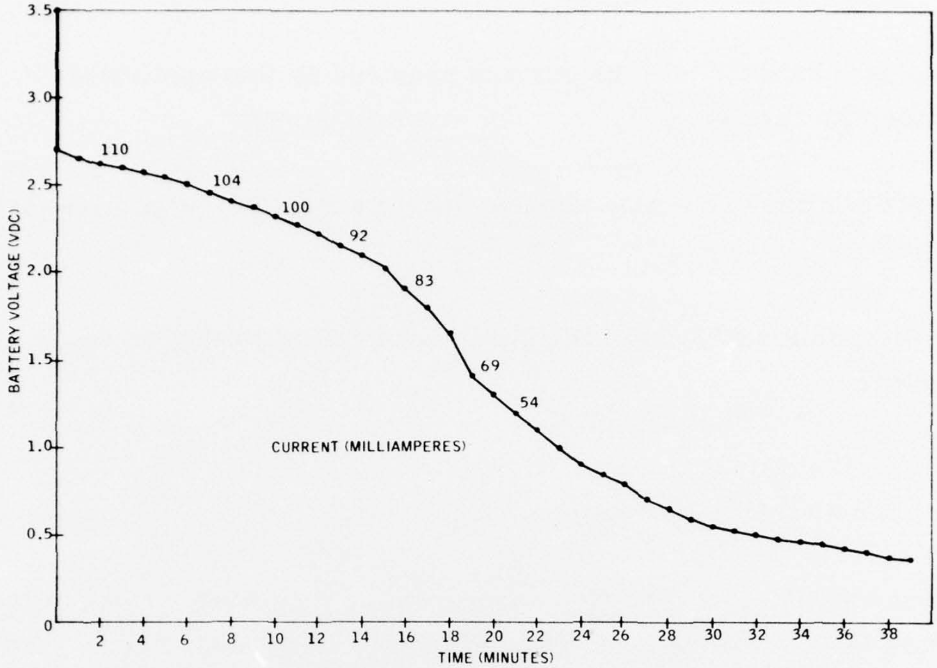


Figure C-1. Single-Cell Battery Voltage Versus Time, 24-Ohm Load, Test 1

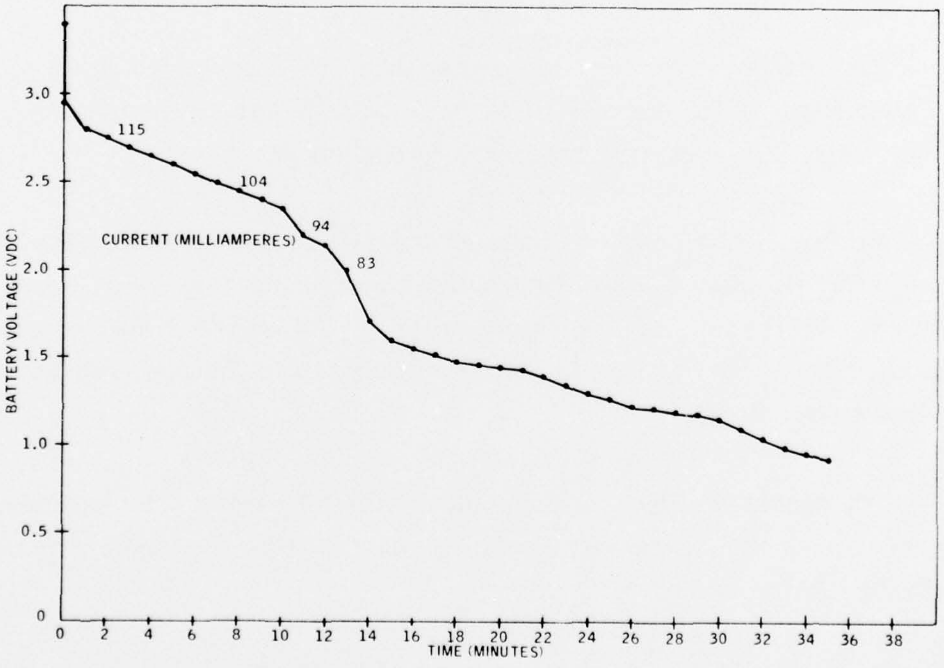


Figure C-2. Single-Cell Battery Voltage Versus Time, 24-Ohm Load, Test 2

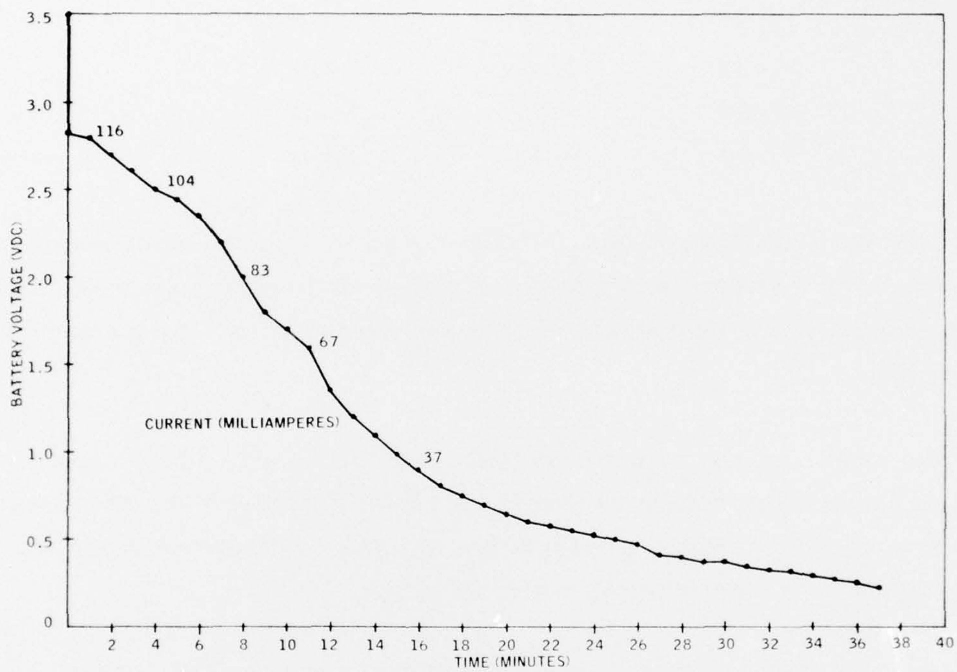


Figure C-3. Single-Cell Battery Voltage Versus Time, 24-Ohm Load, Test 3

The discharge times of the four cells were as follows (see also Figures C-4 through C-7):

Cell Number	OCV (Volts)	Life to 2.00 Volts (Minutes)
11.31	3.57	0.3
11-32	3.53	20.0
11-43	3.38	29.9
11-44	3.51	28.0

These cells were discharged at a 24-ohm constant resistance at room ambient temperature. After discharge of the cells, they were post mortemed in order to inspect the components and then determine cause for the performance of cell 11-31.

None of the cells had any pouch seal leaks. Cells 11-32, 11-43, and 11-44 showed no unusual conditions except for a slight greenish cast on the cathode surface in cell 11-32, which is indicative of some undischarged portion of the active material. It was otherwise almost black.

Cell 11-31 had a cathode which was essentially undischarged, which corresponds to its performance. No discontinuities of leads or connections were found. Adhesion of the cathode material to the collector was normal. Other than the undischarged condition of the cathode, there was absolutely no unusual characteristics within this cell. Due to the simplicity of this type cell, it is unlikely that a defect was overlooked in the post mortem analysis. The cause of failure for this unit is unknown; however, it does not appear to have been a condition within the cell.

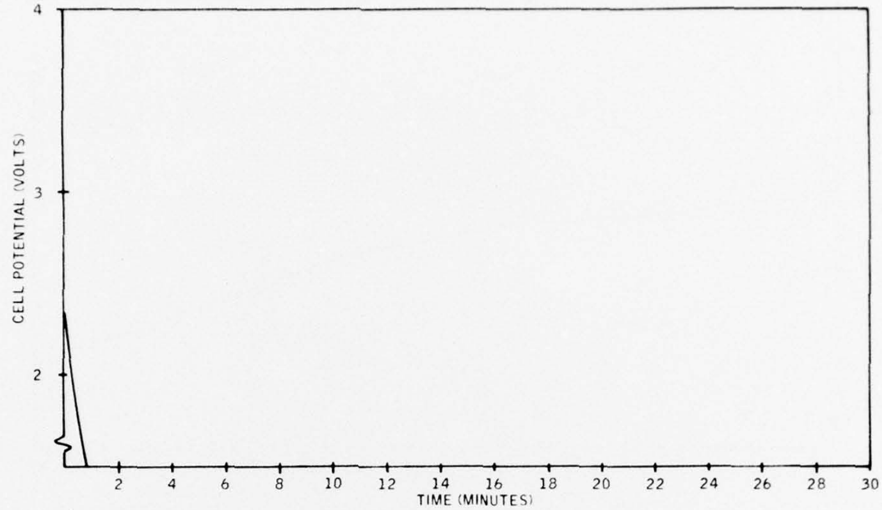


Figure C-4. Discharge Performance of Modified G3004 Cell Serial Number 11-31

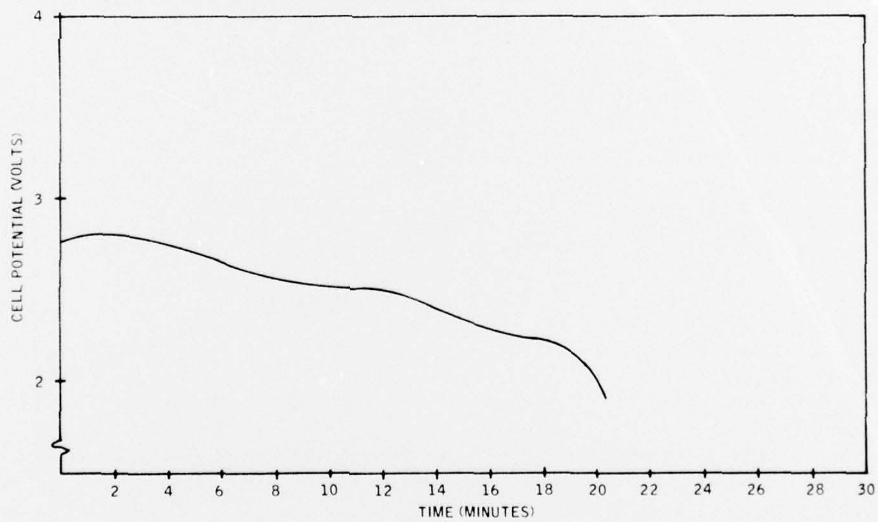


Figure C-5. Discharge Performance of Modified G3004 Cell Serial Number 11-32

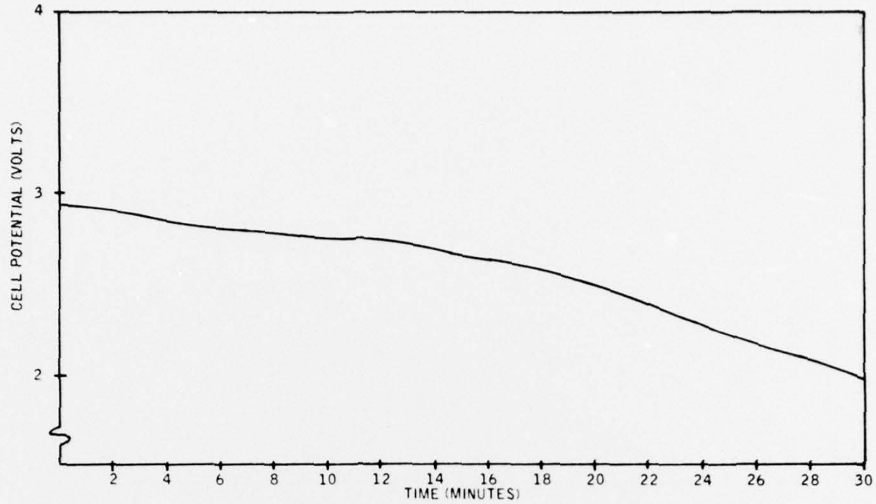


Figure C-6. Discharge Performance of Modified G3004 Cell Serial Number 11-43

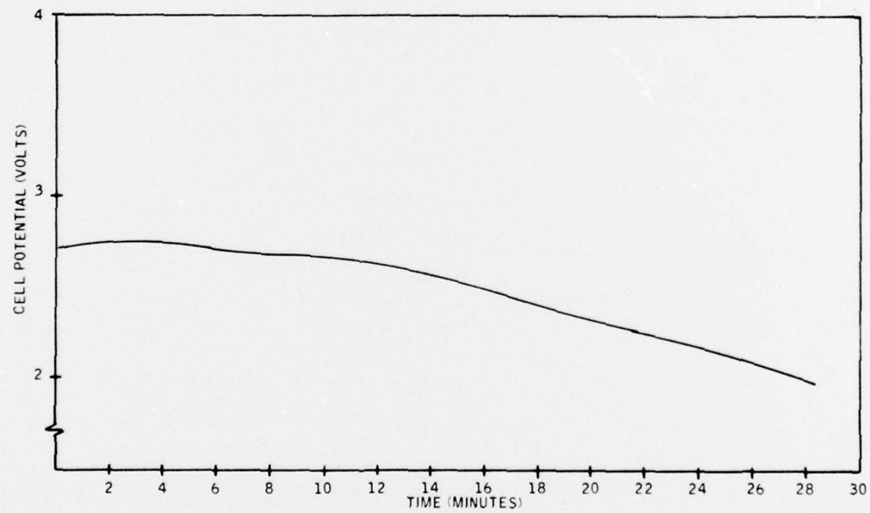


Figure C-7. Discharge Performance of Modified G3004 Cell Serial Number 11-44

A final observation relative to OCV data is made below:

Cell Number	OCV (Volts) (PSC, 12 November 1976)	OCV (Volts) (DSD, 3 December 1976)
11-1	3.48	3.518
11-2	3.51	3.514
11-3	3.49	3.508
11-4	3.51	3.523
11-15	3.53	3.544
11-16	3.52	3.527
11-17	3.49	3.518
11-18	3.51	3.531
11-19	3.50	3.521
11-20	3.49	3.514

All OCV readings made at the later date were equal to or higher than the initial readings. The significance of this is that, if cells show a rapid decline in OCV when in storage, it is indicative of an impairment such as instability due to component contamination. It does not seem to be the case with these cells.

APPENDIX D
FIELD TEST PLAN

INTRODUCTION

Field tests are to be conducted in a field situation to determine performance characteristics of the minisonde. These tests are being conducted as part of Contract N62269-76-C-0368. The tests will be conducted at the Honeywell Test Instruments Division, Annapolis, Maryland.

It is planned that the following tests will be performed:

1. Launching of from one to five minisondes.
2. Receiving and recording minisonde in-flight transmitted data.
3. Partial field reduction of transcribed transmission data to determine performance characteristics.

TEST OBJECTIVES

The objective of these tests is to evaluate minisonde performance in a field situation. The transmitted data from a launched sonde will be received, demodulated, and recorded on magnetic tape to ensure a permanent record and to allow later detailed evaluation of performance. A strip chart recorder will be used during initial tape playbacks to allow a preliminary on-site evaluation of transmitted data.

TEST HARDWARE

Five mini-sondes capable of launch and one breadboard model. The breadboard model will be wired for external power and will be used in setting up the on-site instrumentation.

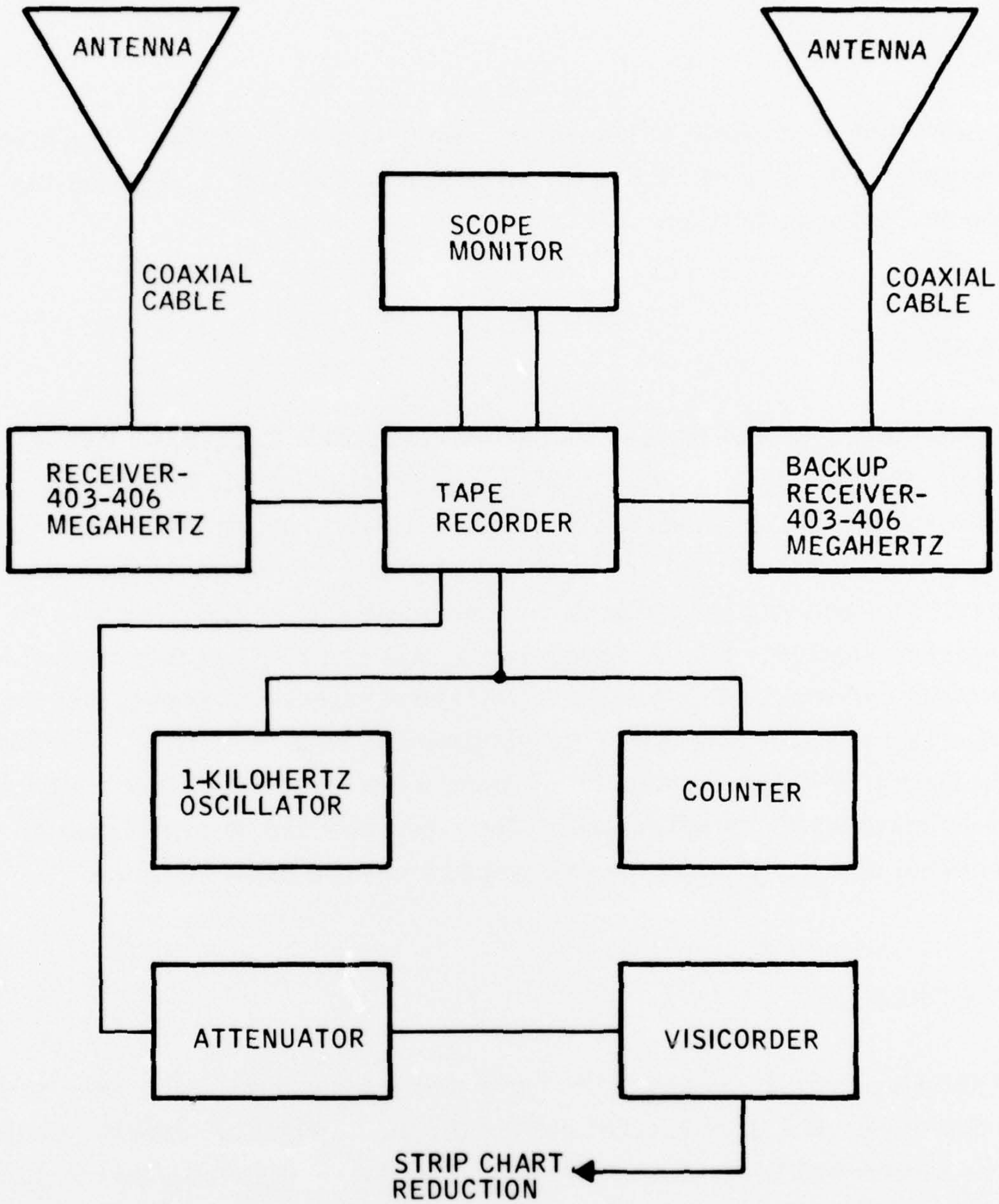
TEST SETUP

A suitable test site will be provided at the Honeywell Test Instruments Division, Annapolis, Maryland. The test site will provide housing for instrumentation and suitable antenna placement. A block diagram of instrumentation is shown in Figure D-1. The received signals from the minisonde are fed from the receiving antennas to receivers capable of demodulating the telemetered signals. The demodulated signals are then fed into a tape recorder and recorded. A 1-kilohertz reference signal will also be fed into the tape recorder for use in on-site preliminary data reduction. The demodulated signals will also be monitored using a dual trace oscilloscope to ensure receiver tracking by visual means. The tape recorded data will then be transcribed on a strip chart for preliminary on-site data reduction.

TEST SCHEDULE

The following test schedule is contingent on all tests being completed in 4 calendar days. If 4 days are not sufficient, the number of launches and/or data reduction will be completed on a priority basis as determined by the customer representative and the mini-sonde Project Engineer.

1. Monday, 14 February 1977 - Unpack instrumentation and set up at test site. Preliminary checkout of instrumentation. Test plan objectives will be correlated with Honeywell representatives at Annapolis.



NOTE: TRANSCRIPTION AND REDUCTION OF DATA ARE POST FLIGHT PROCEDURES.

Figure D-1. Instrumentation Setup

2. Tuesday, 15 February 1977 - Test site inspection and briefing for customer representative.

3. Wednesday, 16 February 1977 - Launch two minisondes, one in the morning and one in the afternoon. Preliminary inspection and reductions of data.

4. Thursday, 17 February 1977 - Launch two minisondes in the morning. Inspect data packup instrumentation. Conclusion of testing.

SPECIAL NEEDS AT TEST SITE

1. Housing for instrumentation - 115 VAC electrical power outlets.
2. Bottled helium with regulator for filling balloons.
3. Backup receiver - Nems-Clarke Model R 1037F or equivalent.
4. Suitable antenna mount.

DETAILED LAUNCH PROCEDURE

Pre-Launch

1. Instrumentation warmup.
2. Set receivers to approximate setting for minisonde to be launched.
3. Set reference signal to 1 kilohertz
4. Check recorder.
    a. Set at 7-1/2 inches per second.
    b. Open "mike."
    c. Check outputs for proper operation.

5. Open up and insert hygristor, tie down top.

6. Fill balloon to achieve an ascent rate of 1000 feet per minute.

Launch

1. Insert switch pin to apply power to sonde.

2. Check receivers for tuning of demodulated signals - maximum signal strength and audio.

3. Turn on tape recorder.

4. Check visual monitor (scope) for fine tuning of demodulated signal.

5. Record ambient baseline data - approximately 10 seconds.

6. Release sonde at T_o.

7. Observe visual monitor and retune receivers as necessary during flight.

8. Maintain audio portion of tape to indicate times from T_o and pertinent details of flight.

Post Launch

1. Properly mark and identify magnetic tapes as to place, date, tape number (flight number), sonde number, recorded speed, and channel information.

2. Enter any and all information pertinent to test in the data book.

3. Transcribe recorded data.

   a. Tape recorder set at 1-7/8 inches per second (slowest speed).

   b. Chart recorder at 25 inches per second.

   c. Attenuate tape outputs to obtain deflection of 1-2 inches on visicorder.

4. Reduce strip chart data - Refer to step 2.